DEPARTMENT OF

SCIENTIFIC AND INDUSTRIAL RESEARCH

GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

EAST YORKSHIRE AND LINCOLNSHIRE

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by

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EAST YORKSHIRE AND LINCOLNSHIRE

I. INTRODUCTION

THE REGION to be described in this handhook extends from the Wash to tbe River Tees aod is limited on its western side by tbe rivers Trent and Ouse. It includes the greater part of tbe couoty of Lincolnshire, the East Riding and eastern balf of the Nortb Ridiog of Yorkshire. Tbe boundary of the area is arhitrary; in the south it extends from Boston westward to Grantham, whence it is traced northward to Newark, aod tben follows the River Trent for a considerahle distaoce northward hefore striking across country to Goole, on tbe Humher. Beyond Goole it runs oorth-westward to the River Ouse at York, tbeoce to Boroughbridge and northward to the estuary of the River Tees.

The scientific aspects of the region have beeo tbe suhject of many valuable contrihutions to koowledge by oaturalists, geologists and other men of science for maoy years; tbese contrihutions are so extensive that it is impossihle bere to give a complete survey of the history of the work that has beeo dooe. It will suffice to draw attention to a few of the outstanding advances made by various workers, more particularly those who are oo looger liviog. In the early days of geological science the Yorkshire Coast was a happy buotiog ground for the fossil collector and the more serious student. William Smith produced tbe first geological maps of Liocolnshire and East Yorkshire in tbe early part of last century. The name of John Phillips is associated with early accounts of the rocks and fossils of the Yorkshire Coast and Tate aod Blake's volume on the Yorkshire Lias is tbe starting point for all work on tbat formation; while the Blea Wyke Beds and the Dogger have received special atteotion over a number of years from Dr. R. H. Rastall. Leckenby was a pioneer in iovestigatiog tbe sandstooes, shales and oolites in the Scarhorough district, while Blake and Hudleston are similarly lioked with Coralliao stratigraphy and palaeontology. Valuahle cootributioos to our koowledge of tbe Upper Jurassic clays were made hy Blake and Roberts, aod Lamplugh's writings on the Speeton Clays bave oever beeo equalled or surpassed. Judd, Hill aod Strabao laid the fouodatioos of our knowledge of the iotricate stratigraphy of tbe Lower Cretaceous deposits; and Jukes-Browne's account of the Chalk stands pre-emineot to the present time. Our knowledge of the Chalk was greatly eobanced wheo Rowe was ahle to extend his scbeme of palaeootological zooes for these rocks in tbe southern counties to Lincoloshire and Yorkshire. Jukes-Browne also took a prominent part in elucidatiog glacial problems, hut the magnificent labours of Lamplugh, Clemeot Reid, Stather aod Kendall will always remain the foundations of future work on glacial problems io Yorkshire.

The present series of Geological Surveys Maps and Memoirs dealiog with this regioo is the work of Fox-Strangways, Jukes-Browne, Barrow, Dakyos, Cameron, Ussber, Clement Reid and Strahan. Amoog this indefatigahle group of geological surveyors, Fox-Straogways stands out as the master of

Yorkshire Jurassic problems. Apart from the illustrious names mentioned above there has always existed a large number of enthusiastic amateur geologists in this region and though their names are too numerous to mention, tribute must be paid to the contributions they have made and are still making.

Geological Formations.—Before discussing the physiography of the region let us consider the general sequence of the rocks, the conditions and events which led to their accumulation, and the subsequent vicissitudes through which they have passed, leading up to the differential resistance offered by the various members of the sequence to the sculptural forces of nature which have produced the present topography. The geological succession for Lincolnshire and Yorkshire is summarized in the following table and the distribution of the rocks is shown in Fig. 1. Detailed accounts of the various subdivisions and their variations throughout the area are given in the ensuring pages.

In Triassic times the climate was hot and arid, and the shales and sandstones of this age in our area probably accumulated in a large basin surrounded by mountainous country. Such surface drainage as existed was internal and of no great magnitude.

By the end of the period the general surface had become more or less a peneplain and the area was invaded by a sea in which the shales, clays, sands, limestones and chalk muds of the succeeding Jurassic and Cretaceous periods were laid down. Throughout these periods the extent and character of the sea was subject to changes and modifications from time to time, and at some stages in its evolution the conditions were sufficiently fluctuating to give rise to rhythmic cycles of deposition. At times, thick masses of sediment were accumulating in one place while elsewhere there was a slowing down or cessation of deposition. These anomalies in the character of the sedimentation and in the palaeogeography of the times are discussed more fully in later chapters. No Tertiary deposits occur in this region, but during that era the adjoining areas were being subjected to earth-movements of great intensity accompanied on the north-west seaboard of the British Isles by igneous activity, in all its phases, on an extensive scale. Few indications of tbis activity are to be found in our area, excepting the intrusion of the tholeiite dyke of Cleveland.

The river systems were probably initiated along west to east lines in early Tertiary times, but the vastness of the subsequent erosion and later modifications of surface detail in the Glacial Period are responsible for the present drainage pattern.

During the Glacial Period much of the area was covered by ice sheets and glaciers. Ice from the north-east extended over part of the Yorkshire coast, the Holderness Plain, and skirted the eastern edge of the Lincolnshire Wolds. During the final stage of glaciation a large glacier from the Pennines and northern England extended down the Vale of York to the vicinity of York.

Except for the vast eastern ice sheet much of the rest of the area was free from ice. Melt waters from the surrounding ice sheets collected in the ice-dammed valleys of Cleveland, which ultimately joined each other and eventually drained into the larger lake which covered the present broad Vale of Pickering. This lake in turn breached the low Howardian Hills

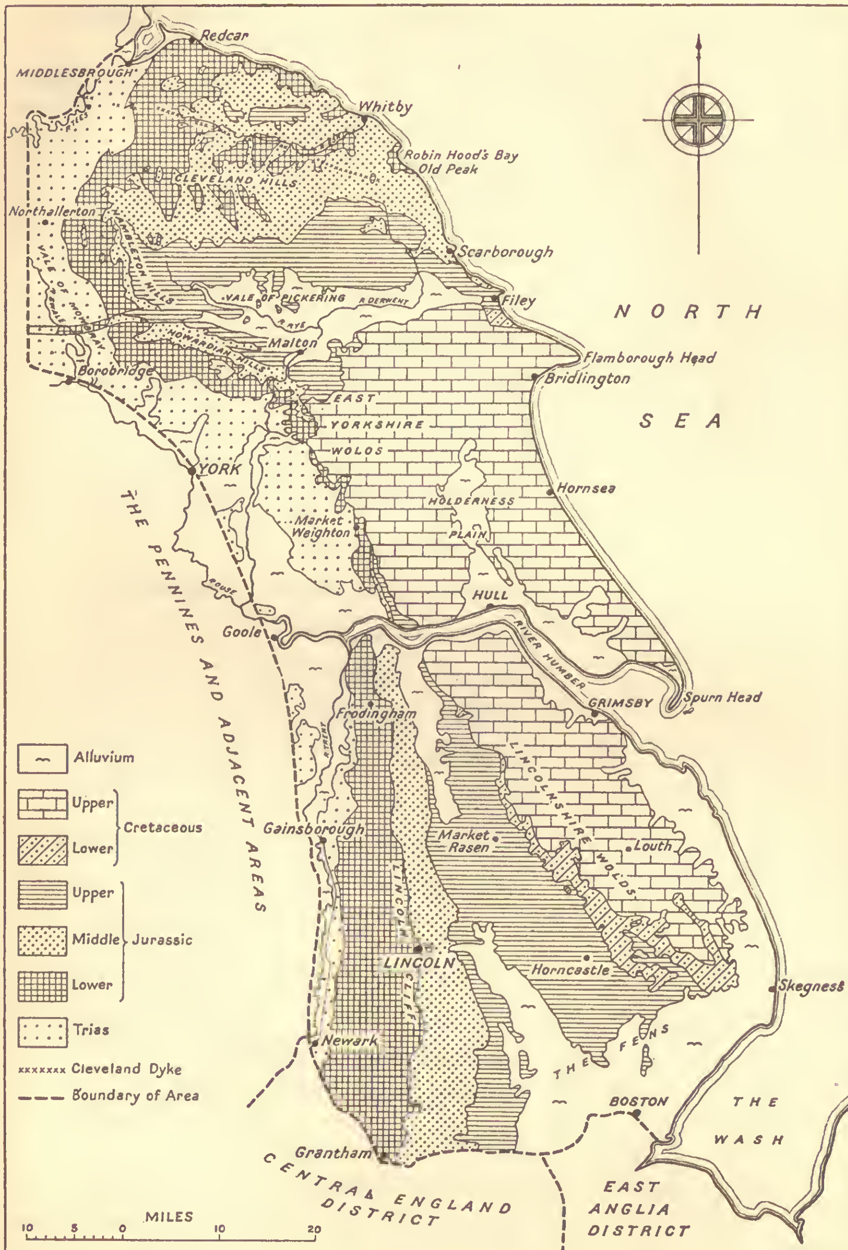

FIG. 1.—*Geological sketch-map of East Yorkshire and Lincolnshire.*

near Malton, cutting the picturesque Derwent gorge and pouring its waters into the vast Lake Humber which occupied all the low ground between the southern Pennines and the western limits of the Cretaceous escarpment. The Lincoln Cliff feature extended northward into this lake as a long,

		YORKSHIRE	LINCOLNSHIRE
QUATERNARY	Recent: Alluvium, Fenland Deposits and River Gravels.		
	Pleistocene: Boulder clays, Glacial sands, gravels and lake deposits.		
TERTIARY	No deposits	Cleveland Dyke.	
CRETACEOUS	Upper	Upper Chalk	Upper Chalk
		Middle Chalk	Middle Cbalk
		Lower Chalk	Lower Chalk
	Lower	Red Chalk	Red Chalk
		Carstone (pars)	Carstone
		Speeton Clay Series	Langton Series
			Tealby Series
			Spilsby Sandstone
		— — — — *Unconformity*	— — — — —
JURASSIC		Kimmeridge Clay	Kimmeridge Clay
	Corallian	Upper Calcareous Grit	
		Osmington Oolite Series	Ampthill Clay
		Middle Calcareous Grit	
		Hambleton Oolite Series	
		Lower Calcareous Grit	
		Oxford Clay	Oxford Clay
		Hackness Rock	
		Kellaways Rock	Kellaways Rock and Clay
		Cornbrash (pars)	Cornbrash
			— — *erosion* — —
			Blisworth Clay
	Great Oolite Series	Upper Estuarine Series	Great Oolite Limestone
			Upper Estuarine Beds
			— — *erosion* — —
	Inferior Oolite Series	Scarborough Grey Limestone	Lincolnshire Limestone
		Middle Estuarine Series	
		Millepore Oolite	
		Lower Estuarine Series	Collyweston Slate
		Dogger	Lower Estuarine Beds
		— — *erosion* — — — —	
			Northampton Sand Series
			— — *erosion* — —
	Lias	Upper Lias	Upper Lias
		Middle Lias	Middle Lias
		Lower Lias	Lower Lias
		Rhaetic	Rhaetic
TRIASSIC		Keuper Marl and Waterstones	
		Bunter Sandstone	

narrow peninsula. During tbis epoch much of the topography was modified and the original drainage systems radically altered, while the area gained mucb land at the expense of the sea. This new land was built by the boulder clays and glacial gravels left here by the ice sheets and its surface details reflect the conditions under which it was formed. Ultimately the climatic conditions began to ameliorate and the end of the Glacial Period was at band. With the final recession of the ice sheets and the draining of the glacial lakes tbe present river systems came into being.

The writer acknowledges, witb thanks, tbe help he has received from various colleagues of the Geological Survey. The preparation of this handbook was begun by Mr. C. E. N. Bromebead, and his notes and other material have been of great value. He and Mr. T. Eastwood have read the manuscript and made many useful suggestions. Professor S. E. Hollingworth and Mr. W. N. Edwards have helped with the chapter on tbe Pleistocene and Recent deposits. The table on page 59 was submitted to and approved by Dr. L. F. Spath, F.R.S. Mr. L. Richardson put at my disposal unpublisbed notes on the Middle Jurassic rocks in Lincolnshire and greatly assisted in preparing Fig. 9 on page 31.

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II. TOPOGRAPHY AND REGIONAL GEOGRAPHY

CONSIDERABLE diversity of topography is to be found, ranging from marshy Fenland only a few feet above sea level to hills reaching over 1,300 ft. in north-east Yorkshire. We shall see how the low-lying tracts are usually underlain by soft, non-resistant rocks while the hills have been carved from the harder rocks. The main physical features and rivers are shown on the sketch-map (Fig. 2, p. 7) and the block diagrams (Fig. 3, p. 8, and Fig. 4, p. 11).

The Lowlands of the Vales of Trent and York.—The western part of the area is formed by a belt of low ground extending from the Tees Valley southward almost to Grantham, over which the Trent and Ouse river systems meander before emptying their waters through the transverse estuary of the Humber into the North Sea. The Trent Valley is over 20 miles wide and its carpet of Pleistocene and Recent material is mainly underlain by Keuper Marl with a border of Liassic clays to the east. Along the eastern side of this valley certain small tributaries of the Trent and the River Witham have incised a series of minor valleys, so that the more resistant beds of the Lias, *e.g.* the Hydraulic Limestone, stand out and give the country an undulating appearance. The Vale of York is similar in many ways to the Trent Valley; northward from the Humber it narrows gradually to the vicinity of Northallerton where the Jurassic scarpland approaches the Pennines. Here a terminal moraine forms a low divide between the drainage southward to the Ouse and northward to the Tees. This constricted northern part of the Vale of York is known as the Vale of Mowbray. Two other morainic bars cross the lowland from the foot of the Yorkshire Wolds near York to the Pennines. The lower parts of the vales of Trent and York were liable to extensive flooding down to historic times and consequently the glacial deposits of these low areas have a veneer of fertile alluvium. South of the Humber is the Isle of Axholme, a low island of Keuper Marl which formerly stood out above the surrounding flooded area of the lower reaches of the Trent.

Lincoln Cliff.—The Broad floor of the Trent Valley rises to the east to a prominent north-south ridge known as Lincoln Cliff (Fig. 3, p. 8). This extends from Grantham almost to the Humber and is remarkable for the regularity of its scarpline which is just over 200 ft. above sea level; it is breached by the Honington Gap at Ancaster and farther north by the Lincoln Gap. The lower slope of the scarp is formed by the Upper Lias, with the Northampton Ironstone and Lower Estuarine beds above, and the Lincolnshire Limestone at the top. The occurrence of springs issuing from the base of the limestone has determined the position of villages on the escarpment. Some surface undulation occurs on the eastern slope of the ridge where the small streams of the Lincoln Clay Vale extend westward in shallow depressions.

Lincoln Clay Vale.—Between Lincoln Cliff and the Lincolnshire Wolds is a second lowland area known as the Lincoln Clay Vale or the Mid Clay

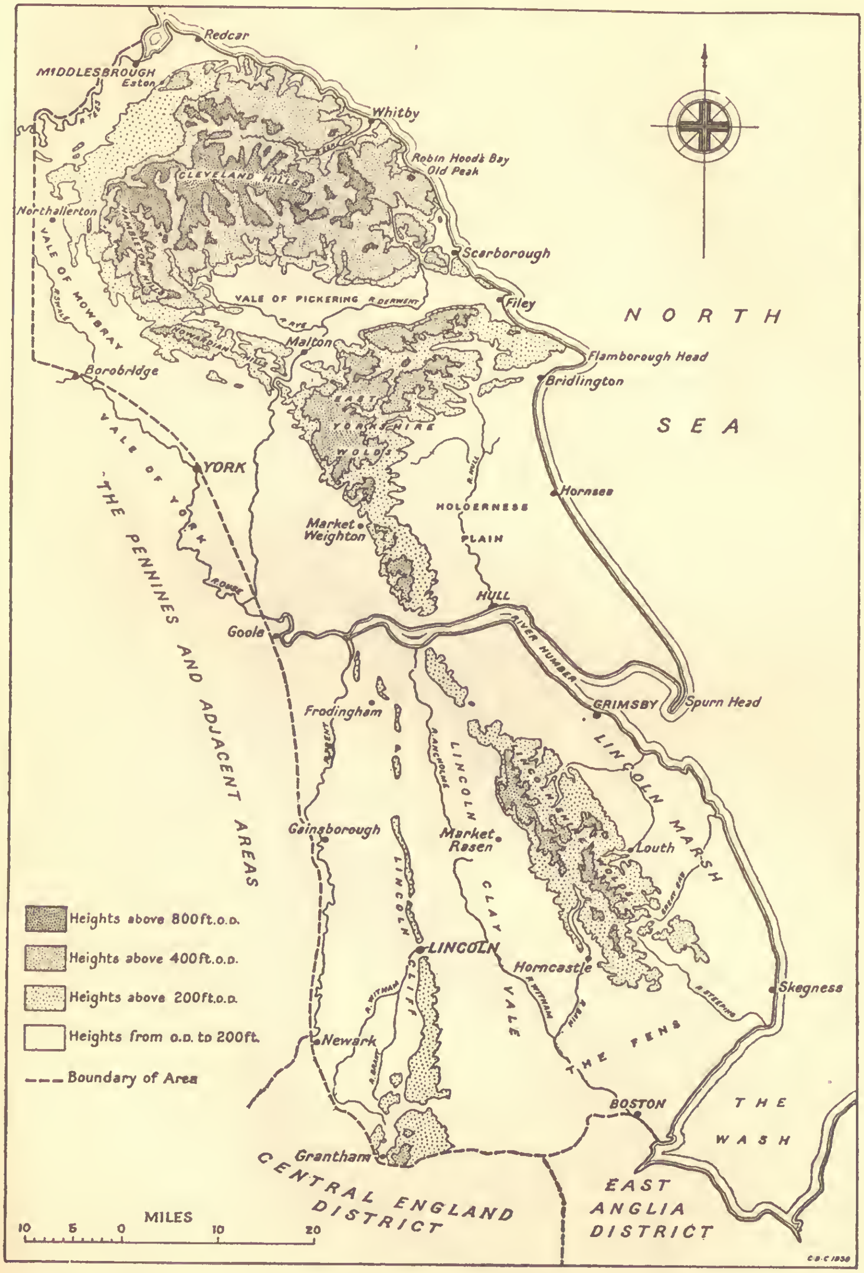

FIG. 2.—*Sketch-map of the physical features of East Yorkshire and Lincolnshire.*

Vale. It extends from the Humber to the Fenlands of South Lincolnshire; in the north it includes the basin of the River Ancholme while the southern part is drained by the River Langworth, a tributary of the Witham. The Vale has resulted from the erosion of the soft Upper Jurassic clays by subsequent streams working southward from the Humber and northward from

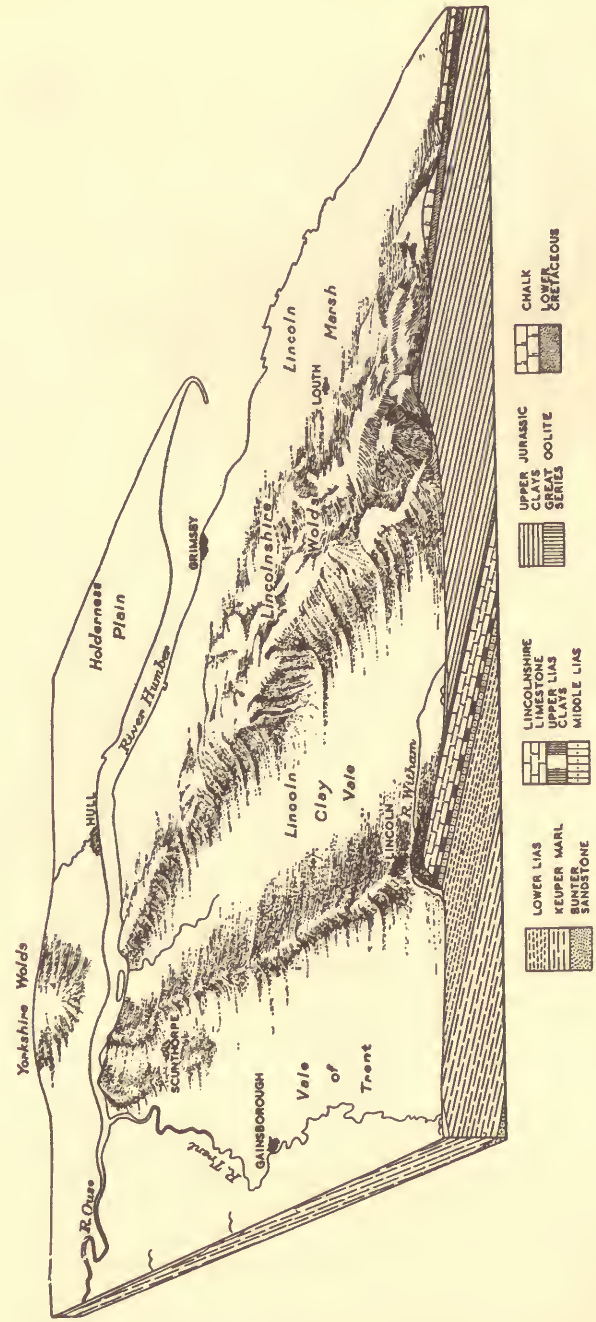

FIG. 3.—*Block diagram of Central and North Lincolnshire.*

the Witham. Its slopes are mantled with glacial deposits which, in the south-east, form a low dissected plateau.

Lincolnshire and Yorkshire Wolds.—East of the Lincoln Clay Vale the ground rises to the Lincolnshire Wolds, a belt of dissected upland from five to eight miles wide and about forty-five miles long, trending north-west across the eastern part of the county and continuing across the Humber into East Yorkshire. The Wolds form part of the scarped Chalk uplands which extend almost continuously from the south of England to Flamborough Head. It is essentially a high tableland of chalk so dissected by springs, streams and other forces of erosion as to give an apparent alternation of ridges and valleys.

To the east, much of it is buried under glacial deposits which have modified some of its original features and also its soils. The Wold escarpment is best developed in the central area where it is fretted by streams; in the south it gradually ceases to be a prominent feature and its drainage is less mature, while in north Lincolnshire it is lower and more regular and has few streams.

Across the Humber the Yorkshire Wolds extend in a crescentic curve rising in places to 800 ft. and end in the bold cliffs at Flamborough Head (*see* Plate 1). On the north they slope fairly steeply down to the broad Vale of Pickering, while on the west a narrow belt of Jurassic rocks prolongs their slope down to the flats of the Vale of York. Deep valleys carrying small streams trench the dip slopes and western escarpment. To the south-east the Wolds decline gently to the hummocky plain of Holderness.

Lincolnshire Fenlands.—The lower portion of the basin of the River Witham in south-east Lincolnshire forms part of the Fenland; which, limited by the 50-ft. contour and of an average elevation of 15 ft. above sea level, is a flat plain of recent marine and alluvial sediments resting on glacial deposits and occupying part of a shallow basin in the underlying Cretaceous and Jurassic rocks.

Lincoln Marsh and the Holderness Plain.—The Fenlands of south-east Lincolnshire pass north-eastward into a flat marshy region up to 10 miles wide extending along the coast to the Humber seaward of the Chalk Wolds, which formed the shoreline in late Tertiary times. On this wave-cut Chalk platform boulder clay and, later, the marine silts of the marsh were laid down. The Plain of Holderness is the continuation of the Lincoln Marsh across the Humber, and the late Tertiary shoreline along the eastern edge of the Lincolnshire Wolds is also continued northward by Hessle and along the foot of the Yorkshire Wolds to Flamborough Head. It has low irregular relief about 10 to 30 ft. above sea level and terminates seaward in a long low unindented line of cliffs averaging 30 ft. in height; its Chalk floor is buried beneath boulder clay, glacial sands and gravels and recent material.

Marshes and meres were once common over this plain but they have long since given place to cultivation and only Hornsea Mere remains.

Areas of boulder clay usually exhibit two main types of topography: featureless ground, usually elevated, and ridges and hollows. The ridges frequently vary in length and may take the form of drumlins. These are generally smooth in profile and oval in plan and their long axes mark the direction taken by the advancing ice; examples may be seen in the western parts of the Holderness Plain and Lincoln Marsh adjacent to the Chalk Wolds. The topography of the country occupied by sands and gravels is much more diversified than that shown by boulder clay and the forms assumed by such deposits largely depend on the variety of local conditions of ice and water under which they were laid down. Many of the gravels are of deltaic origin.

The remaining part of the area, north and east of the Vale of York, presents considerable variation, and five belts of structure and relief are recognized.

Howardian Hills.—The lowland to the north-east of York rises within 12 miles to a series of irregular ridges less than 4 miles wide and nowhere more than 600 ft. in height, known as the Howardian Hills, whose undulating topography has been largely determined by an intricate series of faults.

Vale of Pickering.—The broad alluvial plain known as the Vale of Pickering lies between the dip slope of the Corallian rocks to the north and the Chalk escarpment to the south. It is a flat-floored west to east valley covered by a variable thickness of alluvium overlying the Kimmeridge Clay, the nature of the upper surface of which is unknown. At its eastern end the Vale is cut off from the North Sea by a thick moraine, and in the west it communicates with the Vale of York, via the narrow Coxwold-Gilling Gap—a small trough-faulted valley separating the Howardian Hills from the Hambleton Hills During the Ice Age melt waters from the snow and ice gathered in the Vale and formed an extensive lake which eventually topped the lowest point of the Howardian Hills near Malton and cut the Kirkham gorge leading to the Vale of York.

Cleveland Hills and North Yorkshire Moors.—The dissected plateau between the Vale of Pickering and the northern part of the Yorkshire Coast includes the Cleveland Hills and North Yorkshire Moors. The topographic variations in this sector reflect the nature of the rocks which crop out over its surface much of which exceeds 1,000 ft. O.D., though none of the summits exceeds 1,500 ft. The greater part of it, particularly in the north, consists of dissected hill ranges and long rambling moorland tracts bounded to the north and north-west by a steep erosion scarp. It is an area mainly built of Middle Jurassic sandstones and shales, with Liassic clays and ironstones forming the lower slopes (Fig. 4, p. 11).

To the south this monotonous moorland ceases abruptly at the foot of a well-defined broken escarpment, extending from the coast near Scarborough westward to the Vale of Mowbray, which marks the northern limit of the high, flat country known as the *Tabular Hills*. The general surface of these hills declines very gradually to the Vale of Pickering and is deeply incised by a number of gorges which have been cut by consequent streams flowing southward from the moorlands farther north. The *Hambleton Hills* forming the western part of this plateau terminate in a magnificent escarpment, often developed as cliffs over 100 ft. high, overlooking the Vale of Mowbray to the west.

Rivers.—More than half the area is drained by river systems which flow into the Humber. A few small streams run down the erosion scarp of north-west Cleveland into the River Tees, the River Esk takes a considerable

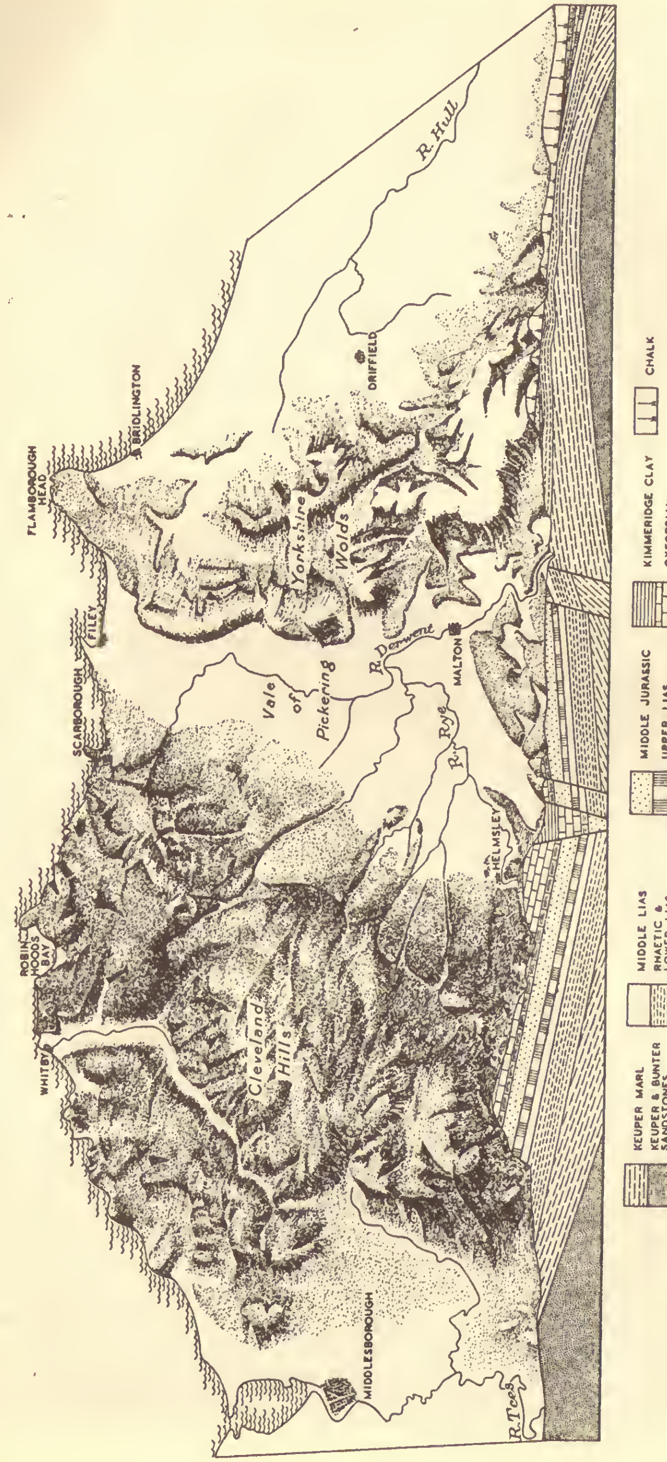

FIG. 4.—*Block diagram of East Yorkshire.*

amount of the surface water of North Cleveland eastward to the sea at Whitby, and the remainder is carried southward by the Derwent and the Hull.

Tbe small streams draining the North Yorkshire Moors above Hackness form the source of the present river Derwent, bnt in pre-Glacial times they flowed out to sea at Scalby Ness, north of Scarborough. Also in pre-Glacial times the drainage from the areas round the Vale of Pickering gathered into a river whose course ran eastward to the sea near Filey. The blocking of these coastal exists by ice and boulder clay ponded these streams and eventually the accumulated water at Hackness broke through tbe hills to the south and cut the present Forge Valley, and later the waters of Lake Pickering breached the Howardian Hills at Malton. Thus the whole of this drainage was diverted through the Kirkham gorge into the Vale of York.

In south-east Yorkshire a small river, tbe Hull, fed by numerous small streams carries the drainage from the Wolds southward across the Holderness Plain to the Humber.

In Lincolnshire, the River Trent flows northward over the western strip of our area but most of its water is drawn from regions farther south and south-west. The only otber river in Lincolnshire flowing into the Humber is the Ancholme draining the northern part of Lincoln Clay Vale.

The River Witbam, in its upper part, flows northward from Grantham at the foot of Lincoln Cliff, but at the city it passes through the Lincoln Gap into the Clay Vale and then follows a south-easterly course to the Wash. Numerous other small streams run off the Lincolnshire Wolds eastward across the Lincoln Marsh to the coast.

The Coast.—Two-thirds of the coastline is made up of simple and regular curves, the result of glacial deposition and coastal erosion; the remaining third bordering north-east Yorkshire is rugged and very irregular. About the Tees estuary the coast is low and flat, but south-east of Saltburn it changes rapidly to high irregular cliffs, at intervals cleft by narrow defiles and small valleys. This line of coast down to Flamborough Head displays mangificent sections of ' solid ' rocks and its interest to geologists never wanes. From near Saltburn, Liassic shales and sandstones form dark, unstable cliffs, but continuing south-eastward the harder Middle Jurassic rocks appear in the tops of the cliffs. Boulby Head near Staithes attains a height of 666 ft. and is considered to be the bighest cliff on the English coast. Towards Scarborough the coast is indented by small ' wykes ' and bays and the cliff line is consequently irregular. Between Scarborough and Flamborough Head a variable thickness of boulder clay overlies the solid rocks, and weathers into characteristic *arêtes*. The Chalk gives rise to the magnificent beadland and precipitous cliffs of Flamborough. The sea-caves and isolated ' stacks ', a feature of the cliffs hereabouts, are due largely to wave action compressing and realeasing the air along cracks or joints assisted by solution of tbe rock. Between Flamborough Head and Spurn Point, the regularity of the coast is due to tbe uniformly soft nature of the glacial deposits and the low cliffs there are being rapidly eroded by the sea. This type of coastline is continued soutb of the Humber as far as the Wash; and throughout Holderness and East Lincolnshire the boulder clay cliffs rarely exceed 30 ft. in height.

THE CHALK CLIFFS OF FLAMBOROUGH HEAD SEEN FROM THE AIR
(*Reproduced by permission of Aerofilms, Ltd.*)

[*To face page* 12

A.—THE CHALK WOLDS IN SOUTH LINCOLNSHIRE

B.—HORNSEA MERE IN EAST YORKSHIRE

C.—THE WITHAM GAP AT LINCOLN

Soils and Agriculture.—The Fenland of south-east Lincolnshire was a region of marshes, meres and sluggish streams until its reclamation by man, who turned it into a rich agricultural land. It possesses a variety of soils; areas of light silts border the Wash while the heavier soils and peat soils, devoted to wheat and potato growing, occur inland. Marine silty soil again borders the sea in the Lincolnshire Marsh area and provides good pastureland; heavy boulder clay soils are found nearer the Wolds where mixed farming predominates. The Holderness Plain is similar to the Lincoln Marsh; many of its soils are clayey and impervious but most of the area is cultivated.

The agricultural conditions on the Chalklands of Lincolnshire and Yorkshire contrast with those of the lower seaward plains. The soil is generally thin and sandy rather than calcareous, flints are numerous and on the eastern slopes it is influenced by the presence of glacial deposits. Though permanent grass is not abundant, these areas are mainly devoted to sheep rearing, and such rotational crops of grain and roots as are obtained from this poor soil are largely the result of much marling and liberal treatment with artificial manures. In many respects the limestone area of Lincoln Cliff is very similar to that of the Chalklands.

Agriculturally the Lincoln Clay Vale and the Vale of Pickering are similar. Both are founded on Upper Jurassic Clays with, in the former, deposits of boulder clay and glacial gravel influencing the soils and, in the latter, a superficial veneer of lake alluvium of varying thickness. Both are liable to winter flooding in many parts, and, as a whole, these areas are mainly devoted to cattle rearing on the rich meadows and some cultivation of cereal and fodder crops.

The Howardian Hills are mainly woodland and pasture, but the limestone slopes bordering the Vale of Pickering are very fertile and yield good grain crops. The same is true of the Tabular Hills area on the northern flank of the Vale, but the moorlands farther north are carpeted with heather and agricultural activity is restricted to the sheltered valleys in Cleveland.

The glacial soils of the Tees Valley, Vale of York and Vale of Trent are varied in character and include some almost barren areas of light sands and of boulder clay, with widespread deposits of river gravels and alluvium on the flood plains of the rivers and in moraine hollows; as a whole this western lowland belt is a fertile agricultural region supporting a large but scattered rural population.

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III. FOUNDATION ROCKS

A FEW years before the last war the search for oil in Britain was intensified, and it was eventually discovered in Carboniferous rocks, at depth, in the east Midlands. Geophysical prospecting work was then carried out farther east over a large part of Lincolnshire and revealed the existence of small, deep-seated, north-west to south-east anticlinal structures under Spital, north of Lincoln; Nocton and Blankney, south-south-east of the town; and Stixwould, farther east near Horncastle. Subsequent exploratory boreholes in these localities and elsewhere proved that below the Keuper were Bunter, Permian and Coal Measures rocks such as occur in the east Midlands, and many details of stratal thicknesses and other interesting anomalies were discovered.

At Foston, near Grantham, it was found that beneath more than 1,000 ft. of Triassic rocks the Permian was only 160 ft. thick and rested directly on 485 ft. of Carboniferous Limestone, with supposed Pre-Cambrian rocks below. Borings at Nocton and Blankney revealed small thicknesses of Coal Measures and Millstone Grit intervening between the Permian and Carboniferous Limestone, the latter being 850 ft. thick and underlain by Cambrian rocks at the former locality. In boreholes at Spital, Dunstan and Stixwould underlying the Permian were Coal Measures over 900 ft. thick with seams of coal 5 ft. thick or more at depths exceeding 4,000 ft. It was also found that at depth in this area the Triassic rocks increase in total thickness towards the east and north-east.

In the northern part of the region similar investigations have been carried out and two important exploratory borings were sunk in Eskdale and in the Cleveland Hills. The former revealed a thick Upper Permian salt deposit and a deposit of polyhalite in the Middle Permian; the latter borehole pierced more than 2,000 ft. of rocks belonging to the Carboniferous Limestone Series. More recently at Fordon, near Filey, a deep exploratory borehole has passed through Mesozoic and Permian rocks underlain by 424 ft. of Millstone Grit.

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IV. THE TRIASSIC SYSTEM

DEPOSITS of Triassic age form the belt of low ground along the western fringe of the region, which includes the vales of Trent, York and Mowbray. Owing to their soft nature and the thick mantle of drift which largely obscures them, surface features are inconspicuous and indeed, the greater part of our knowledge of them is based on borings and pit sinkings. It is interesting to note that a boring at Market Weighton proved Triassic strata down to a depth of 2,129 ft., thus showing clearly the non-existence during Triassic times of the anticline which in the succeeding period had such a profound effect on the sedimentation.

Here we are only concerned with the upper part of the Trias, that is, the Keuper Series, which passes down into the underlying Bunter Sandstones. In Lincolnshire the Keuper is sub-divided as follows:

2. Keuper Marl	:	marls
1. Keuper Waterstones	:	alternating sandstones and marls

In the south the Keuper Sandstone is a thin bed of hard pebbly sandstone resting on the eroded top of the Bunter. The Waterstones are about 250 ft. thick at Newark and Tuxford and diminish northward into Yorkshire. The small arthropod, *Euestheria minuta* (Alberti) is common in these beds, amphibian and reptilian footprints, fish remains and fragments of plants are also not infrequent.

The Keuper Marl has a greater development than the underlying sandy beds and preserves a more uniform character. In North Lincolnshire it averages 850 to 900 ft. thick and consists of dark red marly clays with thin layers of red and, in the lower part, grey sandstones known as ' skerries '. The skerries consist of seams of grey marl and grey sandstones or siltstones varying from dolomitic sandstones to quartzose dolomites. Deposits of gypsum, anhydrite, rock-salt and celestine occur at various levels and represent chemical precipitates in salt lakes. Nodules and lenticular masses of gypsum occur at two levels in Lincolnshire, one at about 60 ft. from the base and the other near the top of the series; the upper gypsiferous beds form small cliffs on the banks of the River Trent at Newton, Laughterton and Gainsborough. Gypsum is also met with at Epworth, Burnham and elsewhere on the Isle of Axholme, an isolated tract of Keuper Marl which has resisted denudation and stands out as a hillock in the marshes of the Trent and Idle.

North of the Humber the Keuper Marl is subdivided as follows:

3. Tea-green marls
2. Red marls with gypsum beds and nodules of anhydrite .. 500–700 feet
1. Red and white sandstones below, formerly referred to the Keuper Sandstone but indistinguishable from the Bunter Sandstone.

Here and there, hills of Trias form distinctive landmarks in the Vale of York; some are formed by the Bunter Sandstone, as at Bilbrough, Hambleton Hough and Brayton Barff, while others consist of Keuper Marl as at Holme-on-Spalding Moor and Crowle.

Bunter Sandstone is exposed in the bed of the River Derwent at Stamford Bridge when the water is low, and is there a greenish sandstone with rounded quartz grains. It has been penetrated by borings at York, Strensall, Fangfoss and Northallerton, and is exposed in the banks of the Tees below Egglescliffe, where it is a thinly bedded red micaceous sandstone.

Keuper Marl is visible in the Derwent Valley from Kirkham Abbey to Stamford Bridge and in the banks of several becks and streams. Red marls and shales predominate with intercalated beds of grey shale and thin sandstones, the under surfaces of which are often covered with pseudomorphs of crystals of rock salt. Layers of fibrous gypsum occur at certain levels and were formerly worked near Scrayingham, at Winton, near Northallerton and at Eston. In the Tees Valley, heds of gypsum, anhydrite and rocksalt are common in the upper part of the Permian, and have heen encountered at depths from 800 to nearly 1,700 ft. helow the surface.

The marine or semi-marine conditions of the Permian period gave place in Triassic times to desert, fluviatile and lacustrine conditions which prevailed over a northern continent, including what is now Britain and much of northern Europe and which had come into being after the deposition of the Coal Measures. During Triassic times the planation of this continent was nearing completion; the high ground had been undergoing erosion for a long time and concomitantly the depressions were heing filled up with sediment. The gradual upward change seen in the lithology of these rocks is related to the corresponding physiographic changes which lasted from Bunter times to the close of the period. The Bunter Sandstones in the north are less coarse than those in the south. Although the material was weathered under arid conditions, there is considerahle evidence that much of the Bunter Sandstone accumulated in watcr. The Keuper Marls were deposited as mud in the shallow saline waters of a central inland sea which frequently dried up. The materials of the Keuper were derived from the surrounding desert where tracts of Carboniferous sandstone, shales, limestones and older rocks were being denuded. This central area of accumulation was subjected to periodic flooding hy widespread ephemeral inundations of fresh water from the bordering hills and uplands. Temporary streams and torrents carried material to the sheets of water occupying the hollows and the desert winds transported finer dust; the resulting deposits formed under such conditions were stratified to some extent. The ' skerry ' bands may he regarded as the coarser deposits of these temporary floods which quickly dried up while the marls were partly formed from the finer sediment carried to the inland sea and partly from dust carried hy the winds. Under the general conditions prevailing the extent and form of this inland sea would change from time to time; at some stages the site may have heen occupied partly hy permanent lakes and partly hy seasonal flood plains, while at other times a continous sheet of water may have existed Again, tbere were intervals of time, varying in duration, when the evaporation of the saline waters exceeded rainfall, the chemical content reached saturation point and precipitation hegan. In this manner the heds of gypsum, rock-salt, and anhydrite are accounted for. Modern parallels for the Triassic conditions are to he found in the Dead Sea area and in the West Australian desert.

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V. THE JURASSIC SYSTEM

Rhaetic

THE lowest strata of the Jurassic System are those which were deposited during the readvance of the sea, known as the Rhaetic Transgression, which took place at the close of the Trias and whose effects are widespread over north-west Europe. These beds are poorly exposed in this area, but where they are visible they rest on an eroded surface of the underlying Tea-green Marls forming the top of the Keuper. The sea, at the time, was generally brackish and the fauna consisted of numerous small and degenerate species. The small size and limited variety of the fauna equally indicate that communication with the ocean was neither free nor complete.

In Lincolnshire the outcrop is largely obscured by superficial deposits, but the Rhaetic beds have been seen from time to time in railway cuttings and other temporary sections. Black shales with thin micaceous sandstone courses and three thin bone beds form the basal beds, and are known as the *Pteria contorta* Shales. The lowest bone bed, consisting of 1 ft. of loose micaceous sandstone, lies at the base, while about 8 ft. higher two more occur within a few inches of each other, and are made up of thin layers of coprolites, eroded bones, fish scales and fin-spines, teeth and small pebbles. The thickness of the *Pteria contorta* Shales around Gainsborough amounts to 26 ft. and the thin sandstones have yielded *Pteria contorta* (Portlock), '*Schizodus*' *ewaldi* (Bornemann), *Palaeocardita cloacina* (Quenstedt), *Modiolus minimus* (J. Sowerby), while *Chlamys valoniensis* (Defrance) occurs near the top.

Lying above the *Contorta* Shales are a few feet of dark blue shales with limestone nodules, known as the White Lias. The nodules are usually crowded with the remains of the little phyllopod crustacean *Euestheria minuta* (Alberti) and small ostracods.

The Rhaetic beds extend across the Humber into Yorkshire and their continuity and thickness (40 to 60 ft.) are uninterrupted by the Market Weighton axis. Their outcrop along the eastern fringes of the vales of York and Mowbray to the coast at the mouth of the Tees is largely buried below superficial deposits. Leafy, black and brown shales with two thin pyritous sandstones comprise the lower 17 ft. of these beds, while the upper 10 ft. consists of light grey shales with a 3-in. band of white argillaceous limestone at the top. The shales above the lower sandy band contain numerous fish scales, and the upper sandy band is packed with '*Schizodus*' *ewaldi* (Bornemann) and crinoid stems. These beds are visible in small sections in the Derwent Valley near Crambe and Howsham, and they form a small scarp feature just east of Northallerton, where they are well exposed. Most of the fossils recorded from these beds in Lincolnshire also occur in Yorkshire together with *Protocardia rhaetica* (Merian).

In Lincolnshire and Yorkshire the top bed of the Rhaetic is a layer of fine silty mud which, from its numerous sun cracks, indicates that it accumulated in very shallow water which temporarily receded for a sufficient length of time to allow the mud to harden and crack.

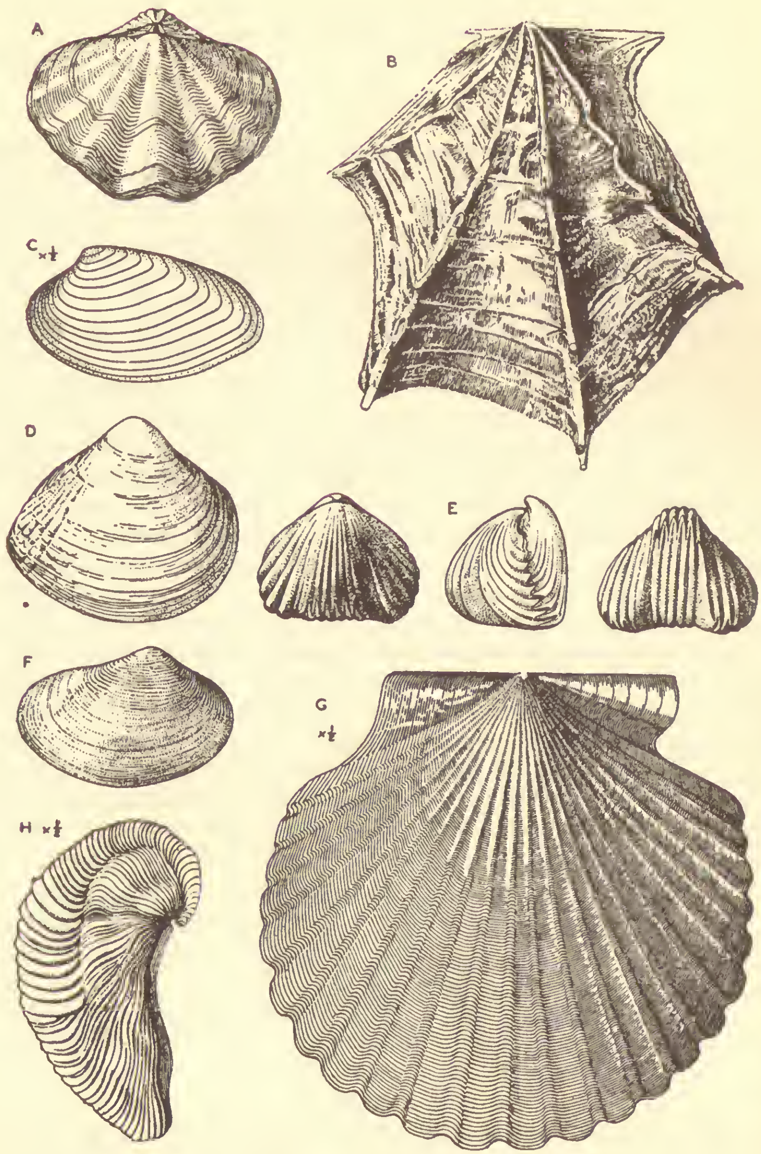


FIG. 5.—*Lias Fossils.*

(All natural size except C, H and G)

A, *Spiriferina walcotti* (J. Sowerby); **B**, *Oxytoma cygnipes* (Phillips); **C**, *Cardinia* aff. *concinna* (J. Sowerby); **D**, *Protocardia truncata* (J. de C. Sowerby); **E**, *Tetrarhynchia tetrahedra* (J. Sowerby) (three views); **F**, *Pleuromya tatei* Richardson and Tutcher; **G**, *Pseudopecten aequivalvis* (J. Sowerby); **H**, *Gryphaea incurva* J. Sowerby.

The bone beds are the most interesting feature of the Rhaetic; they are made up of phosphatic nodules, coprolites, scales, teeth and fin-spines of fish such as *Acrodus*, *Hybodus*, *Nemacanthus*, *Saurichthys*, and teeth of the lung fish *Ceratodus*; eroded bones and teeth of the marine saurians *Ichthyosaurus*, *Plesiosaurus*, *Pliosaurus* and *Trematosaurus*. They do not represent, as has been suggested, a sudden holocaust, but indicate that sedimentation in this extremely shallow sea was almost at a standstill for a considerable interval of time and only the remains of the normal vertebrate fauna were accumulating on the sea floor.

Lias

The formation known as the Lias succeeds the Rhaetic and consists of clays and shales with numerous subordinate ironstones, calcareous mudstones, limestones and sandy bands, all desposited in the shallow, muddy sea which came into being in Rhaetic times. Little or no sandy material was being carried to the sea by the mature turbid rivers which brought only fine mud in suspension. In this environment marine life abounded and myriads of ammonites were present.

These molluscs show well defined evolutionary changes and so have proved invaluable as zonal guides in subdividing not only the Lias but also the whole of the Jurassic deposits. Locally the Liassic sea floor was often carpeted by oysters and elsewhere the waters teemed with ancient cuttlefish the remains of which, known as belemnites, are frequently found massed together in the clays. Apart from the ammonites, oysters and belemnites, the remaining groups of the invertebrate kingdom are poorly represented. But these seas were also inhabited by great marine reptiles; their remains, either as isolated bones or as complete skeletons (Plate IV) are continually being brought to light, particularly along the north Yorkshire coast where the sea is actively eroding these deposits.

The formation is divided into Upper, Middle and Lower Lias, each of which has been further subdivided into ' zones ', or groups of beds characterized by assemblages of fossils, of which one abundant and characteristic form is chosen as the index fossil, though this particular fossil need not be confined to its zone or occur throughout every part of the zone. This scheme of zonal subdivisions, together with the stratigraphical terms applied to the various beds in Lincolnshire and Yorkshire, is set out in the table on page 20.

The Lias shows less variation in its lithological character than the later divisions of the Jurassic System; nevertheless the Market Weighton axis had a profound influence on the thicknesses of the beds laid down in this area, as is shown by the following figures:

	N. Yorks.	*Market Weighton*	*S. Lincs.*
Upper Lias	288 ft.	absent	200 ft.
Middle Lias	265 ft.	absent	95 ft.
Lower Lias	925 ft.	100 ft.	790 ft.

Part of this attenuation is due to erosion of the Lias prior to the deposition of the succeeding Jurassic sediments, but neighbouring sections show that no great amount of Lias was ever deposited in the Market Weighton area.

THE SUBDIVISIONS OF THE LIAS

	ZONES	YORKSHIRE	LINCOLNSHIRE
UPPER LIAS	*Lytoceras jurense*	Blea Wyke Beds *Striatulum* Shales Peak Shales	- - - *Non-sequence* - - -
	Hildoceras bifrons and *Dactylioceras commune*	Alum Shale Series	Shales
	Hildoceras serpentinum	Jet Rock Series	Shales with Nodules
	Dactylioceras tenuicostatum	Grey Shales - - *Non-sequence* - -	Shales Transition Bed
MIDDLE LIAS	*Pleuroceras spinatum*	Part of Ironstone Series	Marlstone and Grey Clay
	Amaltheus margaritatus	Sandy Series with ironstones	Shales with Cementstones
LOWER LIAS	*Prodactylioceras davoei*	Clays with nodules	Upper Clays
	Tragophylloceras ibex *Uptonia jamesoni*	Soft shales with ironstone bands	
	Echioceras raricostatum *Oxynoticeras oxynotum*	Soft shales with nodules and limestone bands	
	Asteroceras obtusum *Arietites turneri* *Arnioceras semicostatum*	Shales with thin limestones	Frodingham Ironstone
	Ammonites bucklandi	Shales with limestone bands	Blue Lias Clays and Hydraulic Limestones
	Scamnoceras angulatum *Psiloceras planorbis*		
	Ostrea liassica *Pleuromya tatei*	Oyster Beds and *Pleuromya* Limestone	

LOWER LIAS

In Lincolnshire the bottom 200 ft. or so of the Lower Lias are blue shaly clays with thin argillaceous limestone bands forming the Blue Lias, of which the basal 25 ft. comprise the Hydraulic Limestones. The lowest beds of the Hydraulic Limestones are mainly fine calcite mudstone with bands of ostracods and foraminifera and are referred to as the ' Pre-*planorbis* Beds ', for while they are part of the Lower Lias their fauna is older than that of the Planorbis Zone. The Pre-*planorbis* Beds in Yorkshire are represented by some 40 ft. of leafy-bedded shales and clays which occur in the Northallerton district and elsewhere. The most characteristic fossils found in these beds throughout the area are *Ostrea liassica* Strickland, *Pleuromya tatei* Richardson and Tutcher, *Modiolus minimus* (J. Sowerby) and *Ichthyosaurus*.

The greater part of the Blue Lias clays and Hydraulic Limestones in Lincolnshire includes the Planorbis and Angulatum Zones and has yielded *Gryphaea incurva* J. Sowerby, *Lima gigantea* (J. Sowerby), *Cardinia listeri* (J. Sowerby) and the zonal ammonites; in north Lincolnshire from Scotter to the Humber shallow water detrital limestones preponderate in the upper beds and give rise to a north-south ridge which marks their outcrop.

Frodingham Ironstone.—At the base of the clays forming the tract east of the limestone ridge occurs a lenticular bed, 6 to 32 ft. thick, of ironstone, which is a much condensed local deposit, representing 200 ft. of beds farther south, ranging from the upper part of the Bucklandi Zone to tbe top of the Obtusum Zone. This ironstone has been actively worked for many years over a large area around Scunthorpe. It is a ferruginous oolitic limestone which loses its oolitic structure on weathering and becomes soft and incoherent. The shells of the lamellibranch *Cardinia* are very conspicuous throughout, accompanied by *Gryphaea* cf. *cymbium* Lamarck, *Lima gigantea* (J. Sowerby), *Pholadomya ambigua* (J. Sowerby), *Spiriferina walcotti* (J. Sowerby), large specimens of *Coroniceras* and various species of *Arnioceras*.

Above the Frodingham Ironstone in North Lincolnshire, the remaining Lower Lias clays thin northward from 210 ft. at Kirton Lindsey to 160 ft. near Appleby, and range from the Oxynotum Zone almost to the top of the Jamesoni Zone (*brevispina* subzone).

About 100 ft. from the top of the Frodingham Ironstone occurs a 4-ft. band of ironstone known as tbe *Pecten* Bed from the profusion of *Pseudopecten aequivalvis* (J. Sowerby) and *Entolium lunare* (Roemer) together with *Liparoceras* aff. *bronni* and other shells including *Cardinia hydrida* (J. Sowerby), *Modiolus scalprum* (J. Sowerby), oysters and brachiopods. The remaining 80 ft. of clays up to the pebbly base of the Marlstone Rock bed have yielded an occasional *Androgynoceras capricornum* (Schlotheim) and all except the top few feet belongs to the Davoei Zone.

The Lower Lias limestone ridge diminishes towards the Humber but reappears again at North Cave as a small escarpment formed by Pre-*planorbis* and *Planorbis* Beds and extends northward to Market Weighton beyond which it is partly overlain by the Chalk and partly obscured by landslips of Chalk. The outcrop then swings westward across the Derwent Valley, along the southern fringe of the Howardian Hills and northward past Thirsk and Stokesley to the mouth of the Tees. Throughout this length it is considerably obscured by drift and apart from small exposures in the Cleveland Hills, the best sections occur along the coast northward from Robin Hood's Bay.

The lithology varies only slightly from one zone to another throughout the sequence, which consists of soft shales with occasional thin bands of ironstone and limestone, lines of clay ironstone, doggers and pyritous nodules. Though not seen *in situ* on the coast, blocks containing *Psiloceras planorbis* are often washed up from submarine scars in Robin Hood's Bay.

The Angulatum and Bucklandi Zones occur at Redcar and in the latter zone is an 8-in. ' Oyster bed ' crowded with *Gryphaea arcuata* Lamarck, together with the corals *Montlivaltia haimei* Chapuis and Dewalque and *M. guettardi* Defrance. Two feet above this is a 3-in. band with *Cardinia listeri* (J. Sowerby). At low spring tides 36 ft. of the Semicostatum Zone with thin shelly seams are exposed in Robin Hood's Bay. The zonal fossil and *Arietites turneri* (J. de C. Sowerby) are fairly abundant, together with *Hippopodium ponderosum* J. Sowerby, *Gryphaea arcuata* Lamarck, *Oxytoma inaequivalve* (J. Sowerby) and various other lamellibranchs. The two succeeding zones, Obtusum and Oxynotum, comprise about 70 ft. of soft grey shales with nodules and calcareous bands, of which the most conspicuous is the ' Double Band ', 2 ft. from the top. From the thin shale above it several species of Oxynoticerates indicating the Oxynotum Zone have been recorded. Since the shales below yield *Asteroceras obtusum* (J. Sowerby) at several horizons, Arkell assumes that most of this 64 ft. of strata belongs to the Obtusum Zone. The Raricostatum Zone, 105 ft. thick, is similar lithologically to the preceding beds, and forms the great arc-like scars on the north and south sides of Robin Hood's Bay.

The succeeding Jamesoni and Ibex zones comprise 102 ft. of shales, the lower 25 ft. being hard and blue, with bands of siderite mudstone while the rest are grey shales. The upper half of these beds yields fragile ammonites of the genera *Platypleuroceras* and *Polymorphites*. Since these forms are recorded from below the horizon of *Uptonia jamesoni* (J. de C. Sowerby) in the Jamesoni Zone of Dorset, it has been concluded that the zone of *Tragophylloceras ibex* (d'Orbigny) and the upper Jamesoni Zone are either absent or represented by unfossiliferous shales in Yorkshire. The zone amonite of the Davoei Zone has not been found in Yorkshire but the occurrence of species of *Oistoceras* and *Lytoceras* serves to indicate that the succeeding 155 ft. of sandy shales are of this age. Two features of these sandy shales are outstanding. Near the top of the zone a hard ferruginous sandstone, 4½ ft. thick, forms the floor of Castle Chamber of North Cheek, Robin Hood's Bay, and contains capricorn ammonites along with *Dentalium giganteum* Phillips and, more rarely, *Protocardia truncata* (J. de C. Sowerby). Some 23 ft. below this bed is an 18-in. bed of thin sandy shales passing into a shell bed composed of *Gryphaea cymbium* Lamarck and *Oxytoma inaequivalve* (J. Sowerby). This bed was originally taken as the base of the Sandy Series of the Middle Lias.

MIDDLE LIAS

Lincolnshire.—The Middle Lias in Lincolnshire comprises a thick lower (Margaritatus) zone of clays, ferruginous and arenaceous in the upper part, and an upper (Spinatum) zone of ferruginous limestone (' Marlstone ') which becomes attenuated and replaced by clay over a considerable area around Lincoln. The series is about 95 ft. thick in South Lincolnshire and thins northward to about 25 ft. at Scunthorpe where it comprises the Marlstone Rock bed, up to 7 ft. thick, with clays below.

The Margaritatus Zone around Grantham consists of 55 ft. of clays with layers of sandy ironstone in the upper part and septariun nodules in the lower part. South of Lincoln, where this zone is only 30 ft. thick the upper limit is marked by a ferruginous phosphatic nodule band, immediately below which the zonal ammonite is found. These clays thin northward to about 17 ft. at Scunthorpe.

The Spinatum Zone or ' Marlstone ' in South Lincolnshire is represented by 35 to 40 ft. of sandy feruginous limestone of which the upper 9 to 16 ft. are developed as ironstone yielding 23 to 28 per cent of iron. Rapid thinning, however, takes place northward and the iron ore has disappeared at Welbourn, 12 miles north of Grantham and some 15 to 20 ft. of clays, with a basal phosphatic nodule bed yielding *Dactylioceras commune* (J. Sowerby), constitute this zone as far as Burton, 2 miles north of Lincoln. Beyond this point the Marlstone reappears as 4 to 7 ft. of feruginous sandy limestone, the lowest 8 in. of which is a loose sandy gravel with bored mudstone pebbles of various sizes and small phosphatic nodules. The brachiopods *Tetrarhynchia tetrahedra* (J. Sowerby) and *Lobothyris punctata* (J. Sowerby) occur in great abundance. This bed with a few feet of overlying clays persists northward to the Humber. The two brachiopods just mentioned are highly characteristic of the Marlstone, and among other common fossils are *Passaloteuthis alongata* (Miller), *Protocardia truncata* (J. de C. Sowerby), *Oxytoma inaequivalve* (J. Sowerby), whereas the zonal ammonite, *Pleuroceras spinatum* (Bruguière) is rare.

Yorkshire.—The northward attenuation of the Middle Lias through Lincolnshire persists across the Humber to the Market Weighton axis. The beds are 16½ ft. thick at South Cave, 9 ft. at Everthorpe Railway cutting and farther north they are just mappable. The Lincolnshire lithological subdivisions cannot be recognized and the series consists of shales with several thin ferruginous limestone bands, yielding the Marlstone fauna and zonal ammonite, but no part of the Margaritatus Zone appears to be present. For a distance of 8 miles straddling the axis there is no trace of the Middle Lias. Farther north, about 30 ft. are present near the Derwent and

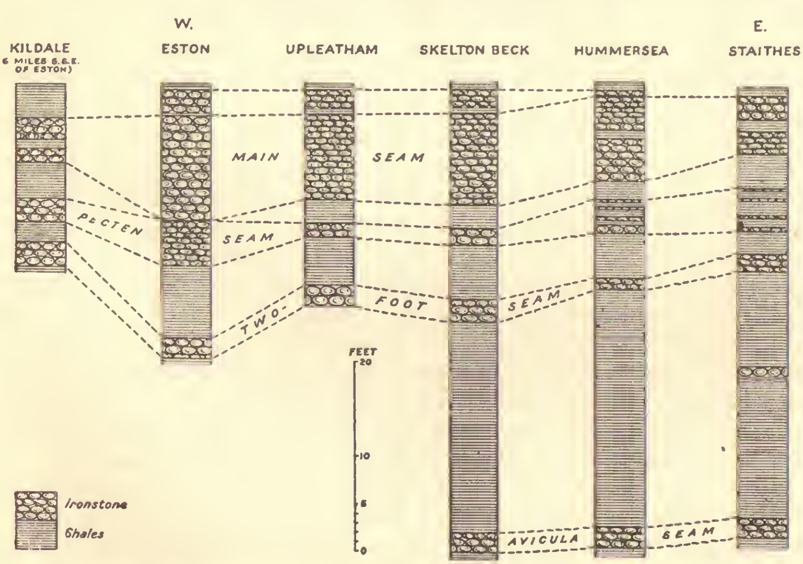


FIG. 6.—*Comparative vertical sections of the Middle Lias Ironstone Series in North Cleveland.*

the thickness steadily increases in that direction to 265 ft., recently proved in a boring in Eskdale.

In the Howardian Hills the Middle Lias is mainly composed of sandy shales and flaggy sandstones with calcareous doggers and yields the common Marlstone fossils, but no ammonites.

In the south-west part of Cleveland the facies changes in the upper part of the series; flaggy sandstones give place to clays with thin ironstone bands which increase in number and thickness to the north-east. Two broad lithological subdivisions have been recognized:

1. Ironstone Series—silty clays and shales witb ironstones.
2. Sandy Series—sandstones and micaceous shaly silts.

Tbe Sandy Series is well-exposed along the coast between Redcar and Staithes and at tbe Peak, where the beds are faulted against Upper Lias beds and give rise to the well known Peak Steel. The series is marked by the great abundance along certain horizons, in descending order, of tbe following shells:—*Protocardia truncata* (J. de C. Sowerby), *Gryphaea cymbium* Lamarck and *Oxytoma inaequivalve* (J. Sowerby). *Dentalium giganteum* Phillips occurs in considerable numbers, while belemnites and *Pecten* are common throughout.

The Ironstone Series has been one of the richest sources of bedded iron ore in England; the individual ironstone seams thicken to the north-west along the northern escarpment of Cleveland and Eston Moor, while the Middle Lias Series as a whole thickens to the east. As a result, the upper 28½ ft. of the Ironstone Series contains 20½ ft. of ironstone in the Eston district and the 11-ft. ' Main Seam ' which is the principal seam worked, is in contact with tbe ' *Pecten* Seam ', 1¾ to 6 ft. thick. The two remaining seams in tbe series, the ' Two-Foot Seam ' and the ' *Avicula* Seam ' occur below the *Pecten* Seam and though they have been worked in the past the ore is of inferior quality. Tbe thinning of the ironstone seams and the development of the shales between them (Fig. 6, p. 23) may be traced south-eastwards along the coast until at Hawsker Bottoms only a much attenuated *Pecten* seam is found amidst many thin bands and rows of ironstone doggers. Typical Cleveland ironstone is an eartby grey rock weathering to ricb brown or red. In places it is densely oolitic, the irregularly distributed pale green ooliths being embedded in a mudstone groundmass. These oolitic ironstones were originally considered to have been oolitic limestones, in which the calcium carbonate had been replaced by iron solution. Hallimond, however, has shown that the bedded ironstones were essentially chemical precipitates, and many of the ooliths are of chamosite, a mineral composed of silica, alumina and up to 41 per cent of iron oxide. The presence of siderite oolitbs is thougbt to be due to replacement of chamosite. The lithological subdivisions of the Middle Lias do not correspond with the zonal subdivisions. The clays with the Main Seam above the *Pecten* Seam have yielded several species of *Pleuroceras* and accordingly they belong to the Spinatum Zone, wbile the remainder of the Ironstones together with tbe Sandy Series are grouped in the Margaritatus Zone. It is evident that the deposition of ironstone began earlier in Cleveland in Middle Lias times than elsewhere in England, where the Marlstone usually coincides with the Spinatum Zone.

UPPER LIAS

The Upper Lias is normally considered to fall into two parts, the Whitbian and the Yeovilian; the former is named from Whitby, where fine cliff sections afford excellent opportunity for study, the latter from Yeovil in Somerset. The ammonite zones included in these two subdivisions are, in ascending order, Tenuicostatum, Serpentinum, Bifrons (with Commune) and Jurense; only the latter falls into the Yeovilian.

Lincolnshire.—Between the Upper Lias and the Marlstone of the Middle Lias is a Transition Bed which in the Lincoln district consists of 2½ to 3 ft. of greenish grey shale, the lower part of which tends to become a sandstone in places. It contains fine ribbed Dactyliocerates throughout and *Tiltoniceras acutum* (Tate) in the upper part. The Upper Lias outcrop is generally a narrow strip of clay land between the Lincolnshire Limestone

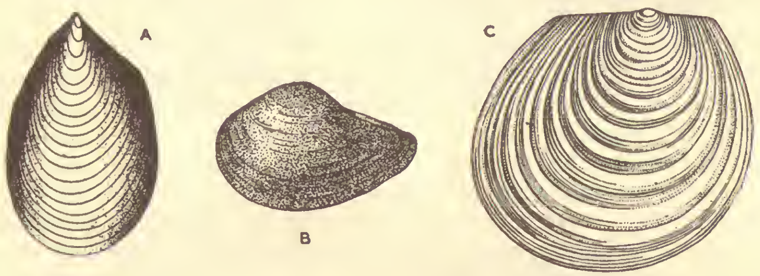


FIG. 7.—*Common Lamellibranchs in the Upper Lias.*
(All natural size)

A. *Inoceramus dubius* (J. de C. Sowerby).
B. *Nuculana ovum* (J. de C. Sowerby).
C. *Steinmannia bronni* (Voltz).

escarpment above and the Marlstone platform below. The principal exposures occur around Lincoln where it has been worked in several brickyards. The series consists, in the lower part, of black shales with lenticular nodules of mudstone, bands of shelly material and thin limestones with fish and insect remains, while blue clays with large septaria and comminuted shell beds containing small gastropods and lamellibranchs comprise the upper part.

All the Upper Lias zones are represented except that of Jurense and the upper part of the Bifrons Zone. Their absence from the sequence is due partly to the removal of material by denudation prior to the deposition of the Northampton Ironstone and partly to non-deposition. The successive zones, from the base upwards, when traced from north to south in Lincolnshire are found to thicken, the upper zones being greatly reduced or absent towards the north (Fig. 9, p. 31). S. S. Buckman, Beeby Thompson and Dr. A. E. Trueman have shown that these variations are the result of the progressive migration southward of the basin of maximum deposition throughout Upper Lias times; the successive stages of this migration are clearly represented in a series of diagrams (Fig. 14) on page 63 of the 1947 edition of ' British Regional Geology, Central England '.

The Tenuicostatum Zone increases from 15 ft. at Grantham to 18 ft. at Lincoln, while the overlying Serpentinum Zone is 24 ft. at Grantham and 35 ft. at Lincoln. In the succeeding Bifrons Zone three subzones (*subcarinata*, *fibulatum* and *braunianum*) have been recognized in south Lincolnshire; of these, the *braunianum* subzone is absent, while the *fibulatum* subzone is 23 ft. thick at Grantham and has disappeared 8 miles farther north. The *subcarinata* subzone maintains a uniform thickness of 50 ft. from Grantham to Lincoln, beyond which it gradually thins out and at Roxby in north Lincolnshire the Lower Estuarine Sandstone rests on beds of the Serpentinum Zone.

Fossils of the Upper Lias include species of *Dactylioceras* and *Harpoceras*, fish and insect remains in the lower beds along with shell beds composed of *Lucina*. Large Harpocerates of the *falcifer* group occur in the Serpentinum Zone while in the higher beds *Dactylioceras commune* (J. Sowerby), *Hildoceras bifrons* (Bruguière), occur along with *Nuculana ovum* (J. de C. Sowerby), *Trigonia pulchella* Agassiz and *Nucula hammeri* Defrance.

Yorkshire.—The northerly attenuation of the Upper Lias throughout Lincolnshire continues towards the Market Weighton axis, and for a distance of 13 miles beyond that anticline these beds are missing; they thicken rapidly north of the Derwent, however, to 80 ft. at Crayke and eventually reach 288 ft. in Eskdale. Throughout Yorkshire the Upper Lias consists of dark shales and clays, indicative of a deeper and more muddy sea than that of the Middle Lias, overlain non-sequentially by the Dogger or basal member of the Estuarine Series. Beds of limestone are almost confined to the base, and the calcareous matter elsewhere is mainly concentrated in bands of nodules, some of which are septarian, while cone-in-cone structure is frequent. The majority of the fossils occur in the nodules, in which they have retained their shape, whereas in the shales they are usually crushed. Ammonites are most abundant, particularly *Hildoceras bifrons* (Bruguière) and *Dactylioceras commune* (J. Sowerby); the former takes its generic name from St. Hilda, the patron saint of Whitby, who, according to legend, slew all the snakes, deprived them of their heads and turned them into stone. The burghers of Whitby have adopted three ammonites as their device. The aptychi of ammonites are also not uncommon; these structures, which resemble flattened bivalve shells, are parts of a double door with which the animal could close its shell.

The Whitbian.—This group comprises the Grey Shales, Jet Rock Series and Alum Shales. The first is 30 ft. thick and constitutes the Tenuicostatum Zone; it is well exposed in the cliffs between Hawkser and Sandsend. The middle part of these soft sandy shales contains several rows of hard calcareous nodules which frequently yield the zonal ammonite along with belemnites, especially the large '*Belemnites*' *cylindricus* Simpson.

The Jet Rock Series consists of about 95 ft. of dark bituminous shales belonging to the Serpentinum Zone; the lowest 25 ft., the Jet Rock proper, is made up of dense black laminated shales smelling strongly of mineral oil when freshly broken. These lowest shales are capped by the Top Jet Dogger, a 4- to 6-inch band of hard argillaceous limestone with large discoidal concretions up to 15 ft. in diameter on its upper surface. This band forms a reef at sea on both sides of Saltwick Bay extending eastward to just north of Whitby Abbey, and is often marked by a line of breakers.

The best hard jet occurs as sporadic lenticular masses in the upper 10 ft. of the Jet Rock. This lustrous black mineral is undoubtedly derived from drifted wood which has undergone decomposition while retaining the

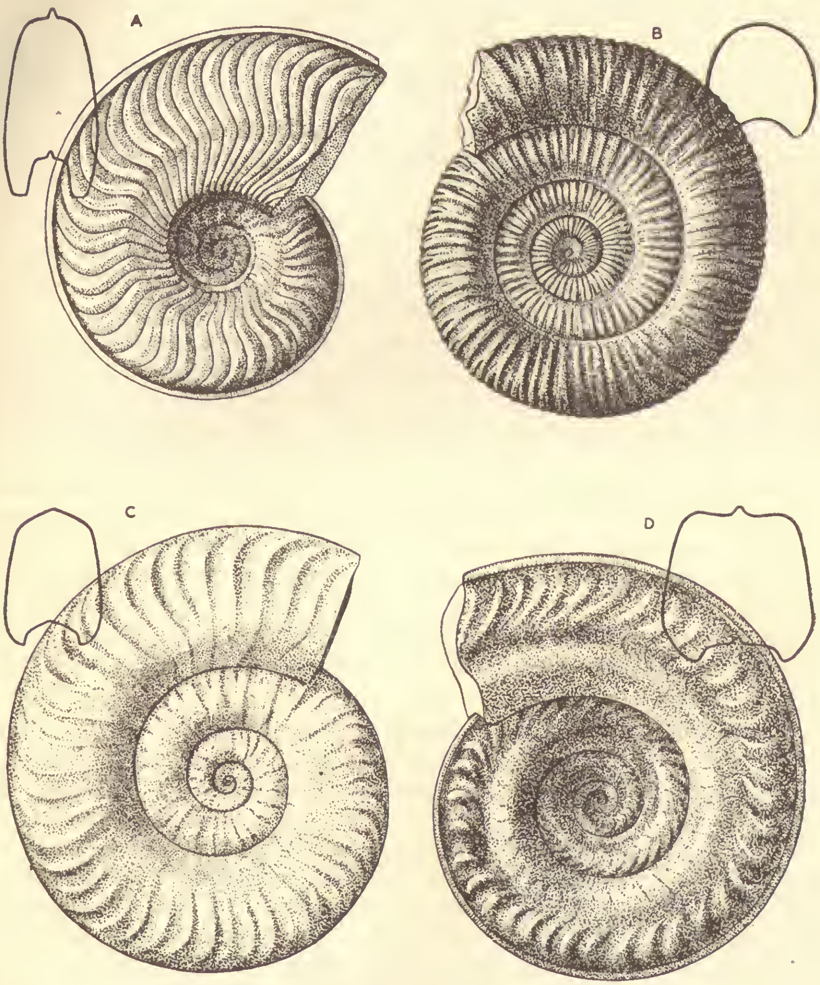


FIG. 8.—*Upper Lias Ammonites from Whitby.*
(All half natural size)

A. *Harpoceras exaratum* (Young and Bird).
B. *Dactylioceras commune* (J. Sowerby).
C. *Grammoceras* aff. *thouarsense* (d'Orbigny).
D. *Hildoceras bifrons* (Bruguière).

cellular structures in a crushed and contorted conditions; it is also noteworthy that spore cases of plants, either wind-borne or drifted, are common in the Jet Rock Series and Alum Shales above. Whitby Jet was worked in the Bronze Age and was pupular in Roman times; magnificent examples of Roman carved jet along with partly worked and unworked blocks have been unearthed in York, indicating that the work was done there. In the middle of last century the mining and carving of jet was an important industry in Whitby, but the little carving now carried on is partly dependent on inferior imported jet.

Ammonites are common in the Jet Rock Series and often contain petroleum in their chambers; the Bituminous Shales, above the Jet Rock proper, are particularly characterized by ammonites of the type of *Harpoceras mulgravium* (Young and Bird), and *Inoceramus dubius* J. de. C. Sowerby is the most common bivalve. The remains of saurians and fish of the genus *Lepidotus* are frequently found and many fine specimens were obtained in the days of jet mining.

The Alum Shales, belonging to the Bifrons-Commune Zone, consist of soft, grey and micaceous shales with a double band of pyritous nodules at the base, in which are occasional masses of siderite mudstone showing cone-in-cone structure and masses of belemnites forming limestones up to 3 inches thick. The nodules contain the ammonite *Ovaticeras pseudovatum* (S. S. Buckman), peculiar to this band and very rare elsewhere in England The overlying 20 ft. of shales, which are almost non-bituminous, are capped by a 5-inch band of siderite mudstone. These are succeeded by 70 ft. of shales which yield large numbers of the zone ammonites *Dactylioceras commune* (J. Sowerby) and *Hildoceras bifrons* (Bruguière), which find a ready sale to visitors to Whitby; the small bivalve *Nuculana ovum* (J. de C. Sowerby), belemnites and many other fossils are common. But these beds are most famous for the large number of saurians found when the alum quarries were working, representing seven genera and some twenty species including five species of *Ichthyocaurus*, three species of *Plesiosaurus*, the great crocodile *Steneosaurus chapmani* (Buckland) and remains of the sturgeon *Gyrosteus mirabilis* Agassiz.

The alum industry began in Yorkshire about 1600 A.D. and continued for some 250 years. Vast excavations were made at Peak, Saltwick, Kettleness, Boulby and elsewhere; the shales were economically quarried near the top of the cliffs and the disposal of the burnt shale also presented no difficulties. Inland, alum shale workings occur along the north Cleveland scarp westward to Osmotherly but these openings were of comparatively small importance. The shale was first calcined over a bed of brushwood, the heaps, sometimes reaching a diameter of 200 ft. with a height of 100 ft., burned for a year or more. The burnt shale was then steeped in water in tanks to extract the sulphates of iron and alumina formed by the action of sulphuric acid, derived from the pyrites, on the shale. To the resulting liquor an alkali was added and on evaporation the alum crystallized before the iron salts, which could then be pumped off. How to ascertain the right moment at which to cease heating the liquor, so that the maximum amount of alum had formed while the iron salts were still retained in solution, was the alum makers' ' secret '. It was done by floating an egg in the liquid!

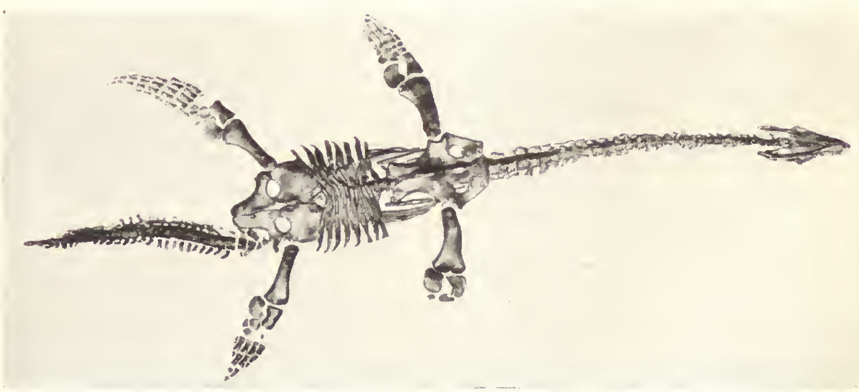
The upper 20 ft. of the Alum Shales, known as the Cement Shales, contains lines of calcareous nodules which were formerly used for hydraulic cement making in the neighbourhood of Mulgrave, near Sandsend. The uppermost chocolate mudstone band of these shales immediately beneath the Dogger at Kettleness has yielded a fragment of a Harpoceratid ammonite

A.—OLD MINE ADITS IN THE CLEVELAND IRONSTONES IN THE CLIFF AT BRACKENBURY WYKE, NEAR STAITHES

B.—THE BLEA WYKE BEDS AND DOGGER AT BLEA WYKE POINT, RAVENSCAR

[*To face page* 28

A.—ICHTHYOSAURUS TENUIROSTRIS Conybeare
(*Extreme width of specimen 6 ft. 3 in.*)



B.—PLESIOSAURUS DOLICHODEIRUS Conybeare
(*Length of specimen 5 ft. 9 in.*)

CHARACTERISTIC MARINE REPTILES OF THE LIAS which dates this band as lying on about the border-line between the Whitbian and Yeovilian.

Inland, the Whitbian crops out round the Cleveland Hills and forms the upper part of the escarpment at Mount Grace; it is also seen in many of the deep dales which cut through the hills, frequently overlain by Yeovilian beds.

The Yeovilian.—The highest Liassic rocks in Yorkshire are mainly interesting for their mode of occurrence. A fault running north-north-east reaches the coast at Peak, below Ravenscar. On the west side of this fault the Dogger rests non-sequentially upon gently folded Alum Shales (Whitbian); higher beds have been found in the Cleveland Dales preserved in troughs beneath the Dogger, but none is present on the coast.

On the south-east or downthrow side of the Peak Fault the Alum Shales are succeeded by Yeovilian beds which pass up conformably into the overs lying Dogger Sandstone at the base of the Middle Jurassic. Here above the Alum Shales are about 60 ft. of dark shales, the Peak Shales, largely obscured by scree and shore boulders, which have yielded species of *Haugia*. They are succeeded by the *Striatulum* Shales—60 ft. of poorly exposed micaceous shales with occasional bands of impure ironstone, from which *Grammoceras striatulum* (J. de C. Sowerby), *G. thouarsense* (d'Orbigny) and other species have been recorded. The Blea Wyke Beds which follow, comprise 38½ ft. of Grey Beds with 30 ft. of Yellow Beds above. The lower part of the Grey Beds consists of 7 ft. of soft grey sandy shales with a basal bed of nodules in which *Lingula beani* Phillips is abundant; these shales pass up into 19¾ ft. of grey micaceous sandstones which are followed by 11¾ ft. of false-bedded *Lingula* sandstones in which nests of the worms *Serpula deplexa* Bean and *Vermicularia compressa* Young and Bird weather out as burr-like masses. The ammonites *Phlyseogrammoceras dispansum* (Lycett), *Hudlestonia affinis* (Seebach) and *H. wykiensis* S. S. Buckman also occur in the Grey Beds.

The Yellow Beds are soft, massive, yellow sandstones with occasional calcareous concretions and abundant worm tubes. They are 30 ft. thick at Blea Wyke but within a mile they thin down to 9 ft. at the Peak Fault. Some finely ribbed *Dumortieriae* have been recorded from the upper part, and on this evidence they are assigned to the *moorei* subzone at the top of the Jurensis Zone. The top of these beds is hardened and bored, and on this surface at Blea Wyke Point lies the irregular 1½-ft. *Terebratula* Bed, which, at the Peak Fault, is represented by a fossiliferous 1-ft. pebble bed. For many years it has been known that the Lias-Middle Jurassic junction was represented by a non-sequence in the Blea Wyke Point section; the recent work of Drs. Rastall and Hemingway has shown that this non-sequence occurs at the base of the *Terebratula* Bed.

The Peak Fault has a throw of about 400 ft., but as nearly 200 ft. of the Upper Lias is present on the downthrow side only, movement along this line of weakness must have been in progress throughout the accumulation of the Upper Lias and overlying Dogger. Movement would be gradual and erosion and deposition on the respective sides of the fault would balance one another. After the Blea Wyke Beds were deposited, more than 20 ft. were eroded before the deposition of the Dogger, which accumulated under conditions of differential subsidence resulting in progressive thickening to the south-east.

Middle Jurassic

Lincolnshire

INFERIOR OOLITE SERIES

The Upper Lias is succeeded by beds which vary greatly both in thickness and lithology, within the area. In Lincolnshire they comprise ironstone (at the base), estuarine sands, limestones, cementstones and clays (Fig. 9, p. 31); while in Yorkshire they consist principally of deltaic deposits interrupted at three levels by marine beds.

Northampton Ironstone.—The Northampton Ironstone is the lowest member of this series in Lincolnshire. It belongs mainly to the Opalinum Zone and lies non-sequentially on the Upper Lias with a layer of phosphatic nodules and eroded Upper Lias fossils, mainly ammonites of the Bifrons Zone, in its basal part. It varies in thickness along its outcrop and thins out eastward; from about 14 ft. near Ancaster it diminishes to about 4½ ft. at Lincoln, but farther east it reaches 12 ft. locally at Greetwell. North of Lincoln it varies between 12 and 5 ft. and towards the Humber it becomes a thin impersistent ferruginous sandstone band. In the southern part of the county it yields 30 to 50 per cent of iron. The heavy minerals of this bed point to a provenance not far distant to the south-east.

Lower Estuarine Series.—In the Grantham district some 16 ft. of stratified sands and clays overlie the ironstone. These beds thin out completely towards a local hiatus at Lincoln, beyond which they soon reappear with a thickness of from 8 to 17 ft. and in the escarpment east of Scunthorpe they are represented by 20 to 30 ft. of buff-grey sandstones which thin northward towards the Humber.

In South Lincolnshire a soft, yellow, micaceous sandstone containing roots of marsh plants occurs above the Lower Estuarine Series. This, the only representative of the Colyweston Slate, is perhaps better included with the Lower Estuarine beds than with the overlying Lincolnshire Limestone. At Ancaster this sandstone has yielded *Gervillella acuta* (J. Sowerby) and *Pinna cuneata* Phillips.

Lincolnshire Limestone.—In the Kettering district of Northamptonshire, the Lower Estuarine Series is followed non-sequentially by the Upper Estuarine Series; northwards, however, beds of limestone intervene and rapidly increase in thickness, attaining in Lincolnshire a thickness of 104 ft. near Sleaford.

The Lincolnshire Limestone, made up of oolites, shelly beds, cementstones and coral beds, is responsible for the straight and abrupt Lincoln Cliff escarpment overlooking the Vale of Trent (Fig. 3).

As far north as Cammeringham, 6 miles north of Lincoln, the lowest beds are fine-grained, blue-hearted, somewhat flaggy, calcareous sandstones (Blue Beds). Above them is a persistent sandy clay band up to 2 ft. thick. South of Lincoln this clay band is succeeded by limestones often rich in the gastropod *Nerinea* and the lamellibranch *Pinna*, and locally massive limestones with scattered ooliths. The Kirton Cementstones, with *Acanthothyris crossi* (Walker), terebratulids, lamellibranchs and other fossils, follow

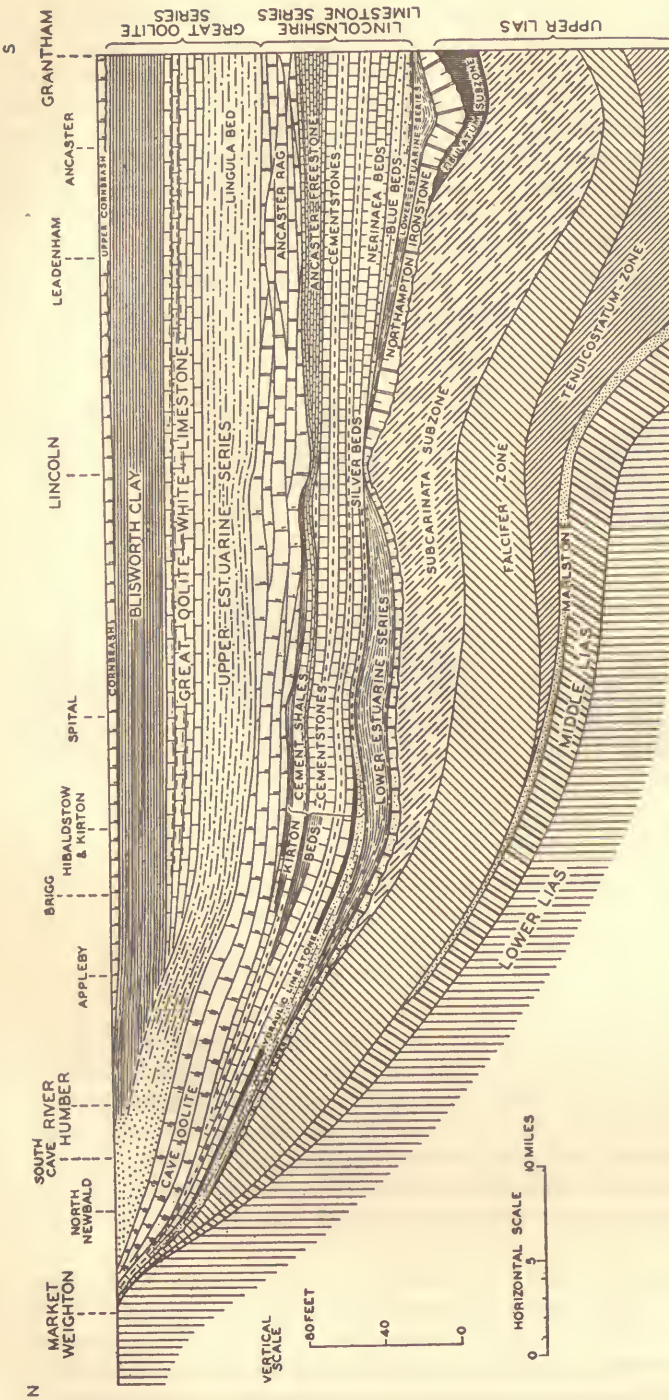


Fig. 9.—Diagram showing the variations in thickness and lithology of the Middle and Upper Lias and Middle Jurassic deposits throughout Lincolnshire,

and are overlaid in the country east of Grantham by the celebrated Ancaster Freestone (15 to 38 ft.) which, locally, at Ancaster, includes a bed rich in corals. The Ancaster Rag, up to 18 ft. thick, overlies the Freestone and completes the Lincolnshire Limestone Series in the Grantham area; the Rag is frequently pisolitic and locally rich in small rolled gastropods which show marked differences from those in the lower beds. Locally, at Lincoln, the lowest beds—Blue Beds—rest non-sequentially on the Northampton Ironstone and the overlying ' Silver Beds ' have yielded a few ammonites of the *discites* subzone. North of Lincoln the Ancaster Rag is known as the ' Hibaldstow Oolite '.

In North Lincolnshire, the Lower Estuarine Series is succeeded by argillaceous shales and limestones, known as the ' Kirton Beds ', with *Acanthothyris crossi* (Walker). At Kirton a fossiliferous coral bed occurs in the lower part of the cement stones and small reef knolls are also frequent near their upper limit. Only the upper 15 ft. or so of these beds are commercially important. Between Scawby and the Humber a local series of buff oolitic marls and thin limestones, up to 15 ft. thick, known as the Santon Oolite intervenes between the brown Lower Estuarine Sandstones and the Kirton Beds, which are followed by the thick, buff Hibaldstow Oolites.

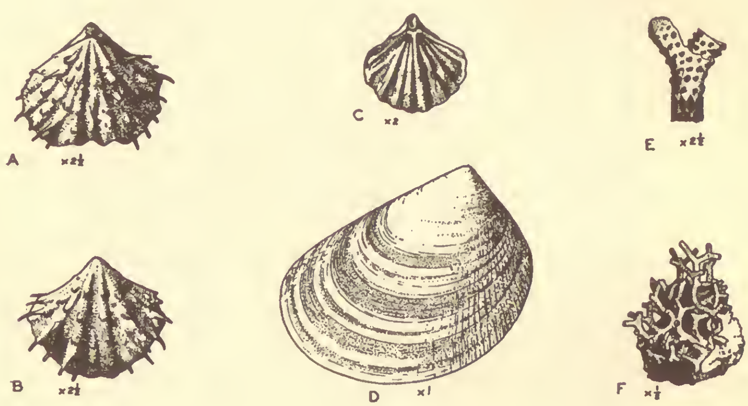


FIG. 10.—*Inferior Oolite Fossils.*

A. and **B.** *Acanthothyris crossi* (Walker).
C. *Parvirhynchia kirtonensis* Muir-Wood.
D. *Lima* (*Plagiostoma*) *rodburgensis* Whidborne.
E and **F.** *Haploecia straminea* (Phillips).

North of the Humber these limestones are represented by the Cave Oolite which rests on the Lower Estuarine sandstones, both of which thin out towards the Market Weighton axis. The scarcity of ammonites in the Lincolnshire Limestone makes its correlation with other deposits difficult; however, the brachiopods appear to indicate that it is equivalent to the Middle and Upper Inferior Oolite, with the base in the *discites* subzone.

GREAT OOLITE SERIES

Upper Estuarine Series.—An Ironstone Junction-bed, which may be a separate deposit or merely the topmost layer of the limestone impregnated with iron, intervenes between the Lincolnshire Limestone and the overlying Upper Estuarine Series. In the Ancaster district where the 30 ft. of Upper Estuarine Series are well exposed, the lowest 9½ ft. is clay, succeeded by dark carbonaceous shales, green clays with white seams of crushed shells and a bed with *Lingula kestevenensis* Muir-Wood, followed by a limestone band. The succeeding 8½ ft. of beds are green and black clays, marls and limestones, with *Ostrea hebridica* Forbes occasionally abundant. Locally, in north and south Lincolnshire, the lower part is a white sand, and north of the Humber this white sand appears to be the sole representative of the series, which dies out between Sancton and the Market Weighton axis. The series amounts to between 20 and 30 ft. in south Lincolnshire, thinning to 15 to 20 ft. in the northern part of the country. Around Lincoln these beds are locally sandy clays and fluviatile clays containing *Viviparus* in the lower part.

It is usually difficult to determine the precise line of demarcation between these beds and the succeeding Great Oolite White Limestone. In mid-Northamptonshire the *Kallirhynchia sharpi* beds constitute the basal part of the White Limestone, but in Lincolnshire this characteristic rhynchonellid has so far only been recorded near Lincoln.

Great Oolite Limestone.—This limestone succeeds the Upper Estuarine Series; its lower part consists of massive limestones which are often locally fossiliferous, while thinner limestones with intercalated marls and clays packed with the oyster *Ostrea hebridica* Forbes comprise the upper part. Its thickness ranges up to 20 ft. with an average of about 15 ft. and it thins out in the neighbourhood of Appleby, a few miles south of the Humber.

Blisworth Clay.—A dark blue clay, frequently mottled green and yielding large oysters (*Ostrea* cf. *hebridica* Forbes) in its uppermost part, overlies the White Limestone. In thickness it varies from 6 to 40 ft. but generally averages about 25 ft.; it dies out between Appleby and the Humber.

Yorkshire

INFERIOR OOLITE AND GREAT OOLITE BEDS

The whole of the Middle Jurassic strata in Yorkshire consists of deltaic deposits with marine beds at three levels—a series of beds covering Inferior Oolite and Great Oolite time and profoundly different from contemporary strata in the Midlands and South of England. In south-east Yorkshire the Market Weighton axis appears to have given rise to a broad, unsubmerged E.-W. ridge in Middle Jurassic times; the attenuation of the various beds of this age against it appears to be a result partly of reduced sedimentation and partly of repeated erosion. Also, contemporary beds on either side of the axis contain different suites of heavy minerals, indicative of their derivation from different sources. North-east Yorkshire, then, may be regarded as the site of a gulf open to the north and north-east, bounded by some slight elevation along the line of the Pennines to the west and connected to an unknown land area to the east by the Market Weighton isthmus. This large gulf was invaded by the deposits of a large delta which advanced from the east and ultimately filled the entire basin.

North of Market Weighton the Middle Jurassic beds first appear near Kirby Underdale; they continue to thicken northward through the Howardian Hills where they give rise to a broad, much faulted, outcrop which is, however, considerably less wide along the foot of the steep escarpment of the Hambleton Hills. Farther north these deltaic beds form the Cleveland escarpment and the broad expanse of moorland which spreads eastward to the coast near Cloughton and Scalby and crop out in the lower part of the cliffs at Gristhorpe Bay.

The Yorkshire basin north of the Market Weighton ridge was steadily sinking, with a line of maximum depression running approximately from

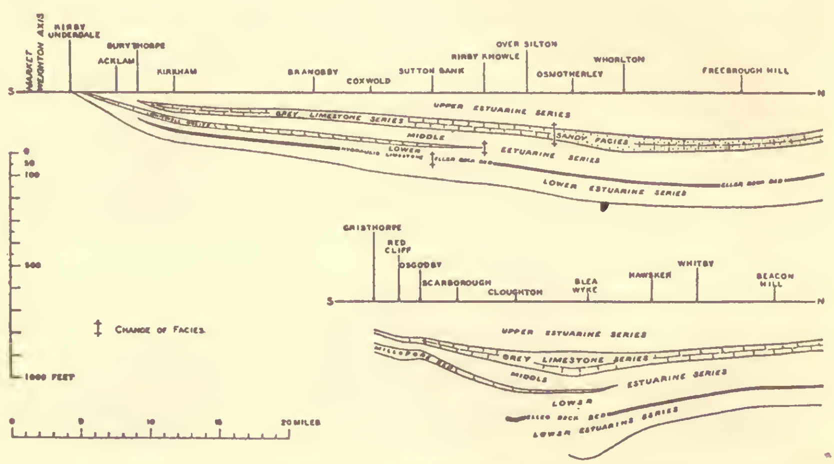


Fig. 11.—*Diagrammatic sections showing the variations in thickness of the Middle Jurassic beds across North-east Yorkshire.*
(After Black)

the Peak on the coast to Burton Howe on the western escarpment. Changes in the character of the sediments near this line are illustrated in Fig. 11. On the coast the Millepore Bed reaches the axis of depression but is not recognizable farther north. On the western escarpment the Eller Beck Bed (ferruginous facies) replaces the Hydraulic Limestone (calcareous facies) near Sutton Bank; the Whitwell Oolite, which is the equivalent of the Millepore Bed, dies out near Kirby Knowle, about 3 miles farther north; and finally, the calcareous development of the Grey Limestone Series gives way to a more gritty (northern) facies some 5 miles north again, between Over Silton and Osmotherley. These changes take place successively northwards in a strip of country 8 miles wide and lying just south of the crest of the Cleveland Anticline. The sequence of the Middle Jurassic deposits on the coast is shown below.

The beds between the Upper Lias and the Lower Estuarine Series proper have usually at least one well-marked surface of erosion. Often there is another erosion surface, slightly above the base of the Lower Estuarine Series; this cuts through the lowest Estuarine beds into the Dogger and in some places into the Alum Shale below. The marine beds which are found between these two erosion surfaces show a wide range in lithology, but for convenience are grouped together under the name ' Dogger '.

		Ft.
	(Upper Cornbrash)	
	— — — — — — *Non-sequence* — — — — — —	
Upper Estuarine Series	Mudstones, shales and sandstones, dominantly level bedded, with a variable thickness of strongly current bedded sandstone and shales at the base	160
	Moor Grit: current bedded grit and quartzite ..	40
Grey Limestone Series	Impure limestone, sandstone and shale: marine ..	104
Middle Estuarine Series	Shales and sandstones with occasional coaly beds	72
Millepore Bed	Calcareous and ferruginous sandstones with nodular beds above; marine	14
Lower Estuarine Series	Shale and thick current bedded ferruginous sandstone (' Estuarine Beds ')	110
	Eller Beck Bed: thin flaggy ferruginous sandstone, resting on shales and ironstones; marine	15
	Carbonaceous shales with thin coal seams in the upper part, large lenticular masses of current bedded sandstone in the lower part (' Estuarine Beds ')	160
Dogger	Sandstones and oolites with the lenticular *Nerinea* Bed, and the *Terebratula* Bed at the Base. Max. thickness	40
	(Upper Lias)	

Whereas in most of the coast sections the highest Liassic beds were removed before the deposition of the Dogger, several remnants in parts of Cleveland show that the marine shales of the Lias pass gradually upwards into plant-bearing beds of Liassic age. In the following account the three cycles of marine beds which are adopted as datum-levels are dealt with first, and then the sediments of deltaic origin.

THE MARINE BEDS

Dogger.—At Blea Wyke, south of Robin Hood's Bay on the Yorkshire coast, the Dogger comprises 40 ft. of green sandstone and chamosite oolites with the 1½-ft. *Terebratula* Bed at the base and including the lenticular *Nerinea* Bed about 10 ft. from the top. The *Terebratula* Bed is a sandy, oolitic ironstone in which ' *Terebratula* ' *trilineata* Young and Bird is common, along with an occasional *Trigonia ramsayi* Wright and *Gresslya donaciformis* (Phillips). The lowest 1½ ft. of the succeeding 27½ ft. of sandstones is an impure micaceous ironstone; the green sandstones contain scattered chamosite ooliths and two 3-in. pebble beds. The 1-ft. *Nerinea* Bed above is a local lens of shells and coral debris from which the following fossils have been recorded:—*Nerinea cingenda* (Phillips), *Astarte elegans* J. Sowerby, *Pseudomelania lineata* (J. Sowerby), *Cucullaea cancellata* Phillips, *Gresslya abducta* (Phillips), *Pteroperna sp.*, *Trigonia v-costata* Lycett and a number of corals of the genera *Montlivaltia* and *Thecosmilia*. This bed is more richly fossiliferous than the shelly limestones in the hills west of Bilsdale and is unlike any other development of the Dogger in this part of Yorkshire. The Dogger at Blea Wyke Point is completed by 10 ft. of chamosite oolite.

North west of the Point the Dogger is reduced to 27 ft. at the Peak Fault; within this short distance the *Terebratula* Bed has passed into a thick pebble bed, the green sandstones are replaced by chamosite oolite, and the upper 10 ft. of chamosite oolite is replaced by sideritic sandstones with a basal pebble bed.

West of the Peak Fault, the Dogger rests non-sequentially on the Alum Shales and varies in thickness from 4 in. up to 12 ft. Two principal facies variations are recognized, (*a*) sideritic sandstone from Peak to Kettleness, and (*b*) oolitic chamositic sandstones and chamosite-oolites with a siderite matrix from Kettleness to Boulby. In the Mulgrave-Sandsend district it is fossiliferous and has yielded a fauna of upper Opalinum Zone (Lower Aalenian) age. Elsewhere in North Yorkshire the Dogger is not always a recognizable bed but is often conspicuous as a 5-ft. band of calcareous ironstone.

Ammonites obtained from feruginous shales usually included in the Dogger in the moorland dales have enabled Mr. W. E. F. Macmillan to refer these beds to the Jurense Zone. In Glaisdale, Trucky Rock Hole west of Whitby, and elsewhere, the Dogger has yielded ammonites characteristic of the upper part of the Opalinum Zone; while at Loftus and in the hills west of Bilsdale it is of later date and yields species characteristic of the Murchisonae Zone.

In the Howardian Hills the Dogger has an extremely irregular distribution and when present consists of ferruginous shelly sandstone with abundant cementstone pebbles in the lower part. In the Derwent Valley and around Terrington it is about 12 ft. thick and has been used for road metal and building—Sheriff Hutton Castle was built of this stone in the eleventh century. South-east of the Derwent Valley it becomes much thinner and is scarcely recognizable beyond Acklam.

Eller Beck Bed and Hydraulic Limestone.—The Eller Beck Bed is found some 100 to 150 ft. above the Dogger, and where the Millepore Bed is absent it provides a useful plane of reference. Lithologically it consists of ironstones, ferruginous sandstones and shales, frequently crowded with marine fossils, mainly lamellibranchs; characteristic forms are *Astarte minima* Phillips, *Pleuromya*, *Gervillella* and species of *Pholadomya*.

On the coast the Eller Beck Bed is not seen south of Iron Scar, between Cloughton and Hayburn Wyke. In the western escarpment it can be traced southwards to the neighbourhood of Sutton Bank, where the ferruginous facies is replaced by a calcareous one. From this point southward into the Howardian Hills this marine band is known as the Hydraulic Limestone. Though not as a rule well exposed, it contains a distinctive band of fine-textured, grey argillaceous limestone which breaks with a conchoidal fracture, and consequently, the few fossils it contains are not easily extracted.

Millepore Bed and Whitwell Oolite.—The reefs and scars off Yons Nab, north of Gristhorpe Bay, are formed from the Millepore Bed, which consists of calcareous sandstone with an abundance of crinoid ossicles and fragments of the bryozoan *Haploecia straminea* (Phillips). Northwards, it becomes less calcareous and more ferruginous, and passes finally into unfossiliferous sandstone.

In the Howardian Hills, this marine band appears to be represented by a strong while oolitic limestone, the Whitwell Oolite. The same bryozoan is present, but not common, and the rest of the fauna is curiously different from that of the Millepore Bed on the coast, especially in the absence of gastropods, and the greater variety of echinoids and brachiopods. The Whitwell Oolite and Millepore Bed contain but few species on which the age of the beds can be determined. The spinose rhynchonellid, *Acanthothyris crossi* (Walker), found in the Lincolnshire Limestone, occurs in the Whitwell Oolite, which may thus be of *discites* subzone date.

The Grey Limestone Series.—This series rises from the sea in Gristhorpe Bay and is seen in the nearby cliff of Yons Nab, where it is about 7 ft. thick. At White Nab, south of Scarborough, it is considerably thicker and includes several hard ironstone and limestone bands, on the surface of which *Gervillella scarburgensis* (Paris) may often be seen in great abundance. Other fossils common at this locality are *Pseudomonotis lycetti* Rollier, *Trigonia signata* Agassiz, *Lopha marshii* (J. Sowerby), and several species of belemnites. North of Scarborough, these beds reappear at Hundale Point, near Cloughton, where they are well exposed and highly fossiliferous. The lower part contains impure limestone bands with abundant *Gervillella* succeeded by sandy marls, grits and calcareous sandstones containing large numbers of crinoid ossicles; the upper part is principally shaly with man fossils, including an abundance of belemnites and a few ammonites. At Blea Wyke, the series is still thicker, largely owing to the presence of flaggy sandstones with *Pleuromya*, which appear both at the top and bottom of the section. The higher sandstone can be traced for a considerable distance inland, where it is characterized by the presence of a small species of *Gryphaea*.

In the Howardian Hills, the Grey Limestone Series is about 40 ft. thick and consists of brown porous grits overlying hard siliceous flaggy limestone. The usual fossils are quite plentiful in this area.

The Grey Limestone Series has yielded a number of ammonites which indicate that the beds as a whole probably belong to the *blagdeni* subzone, but it is possible that other zones are also represented.

THE DELTAIC BEDS

The term ' Estuarine Series ' is misleading when applied to the Middle Jurassic of Yorkshire, since the facies here is characteristically deltaic, and the beds are strikingly similar to the Coal Measures, even to the presence of wash-outs. The fauna is scanty but freshwater lamellibranchs occur at certain places, for example, *Unio kendalli* Jackson in the Lower Estuarine beds at Saltwick; *U. hamatus* (Brown) and *U. distortus* Bean in the Upper Estuarine beds at Gristhorpe, Burniston and near Scarborough. This last shell is of interest as it is almost certainly a *Margaritana* or pearl mussel, and shows eroded beaks like those of the living *M. margaritifer* (Linné), abundant in the River Esk near Glaisdale. Presumably the conditions of life demanded by the fossil species were similar to those required by modern species, namely, acid waters containing little or no lime. The river whose delta is represented by the Estuarine Beds must presumably have drained an almost limeless land area. Insect remains also have been collected from the drifted plant beds at Scalby Wyke. Fossil reptilian footprints are known from several localities, including Saltwick, Burniston Wyke, at Bloody Beck, in the Fylingdales Moor and at Loskey Beck, in Spaunton Moor north of Kirby Moorside, but no traces of bones have been found. Autochthonous plant-beds and coal seams, each resting upon a seat-earth full of ramifying roots, are frequent and several ecologically distinct types are recognized. The simplest and most frequently occurring plant community is a pure growth of *Equisetites*, good examples of which may be seen in the lower part of the Staintondale Cliffs. In the upper part of other plant-beds, *Equisetites* is replaced by ferns, such as *Coniopteris hymenophylloides* (Brongniart), *C. arguta* (Lindley and Hutton) and *Cladophlebis denticulata* (Brongniart). Plant colonization of the delta flats thus usually started with *Equisetites beani* (Bunbury) or *E. columnaris* (Brongniart), followed by some species of fern, and it is only rarely that a more varied vegetation occurs spread over the delta. At two or three levels in the Middle and Lower Estuarine Series, however, beds of a similar type are found, but with an extremely rich and varied flora. It is from these deposits at Gristhorpe, Cloughton and Hayburn Wyke that most of the finest specimens of plants from the Estuarine Series have been collected. Drifted plant remains are particularly important in the Upper Estuarine Series, where the large fronds are usually found in the sediments filling distributory channels, and the smaller leaves and fronds in laminated sediments apparently deposited in shallow lakes on the delta surface.

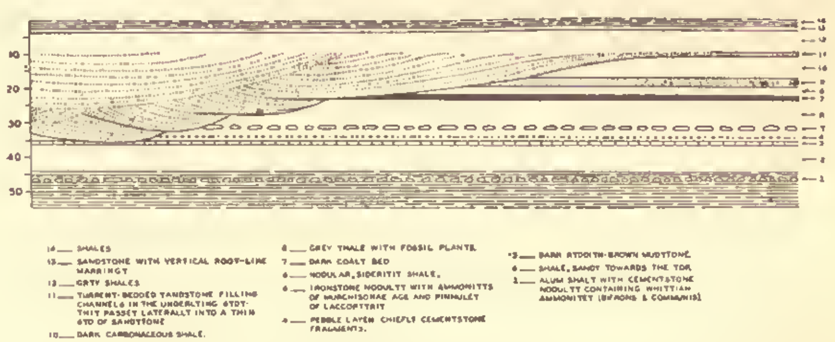


FIG. 12.—*Section at Loftus Alum Quarries showing the position of the Pre-channel Plant Bed.*
(After Black)

Lower Estuarine Series.—The best known of the earliest plant-beds are the *Thinnfeldia* Leaf-bed at Roseberry Topping and that in the Loftus and Boulby Alum Quarries; their plants suggest relationship with Lower rather than Middle Jurassic floras. The former rests directly on the Alum Shale while the latter overlies shale containing ammonites of the Murchisonae Zone (Fig. 12). The infilled river channels of the wash-outs are one of the most conspicuous features of the lowest Estuarine beds in the coastal area; they frequently cut into the basal beds and in many instances

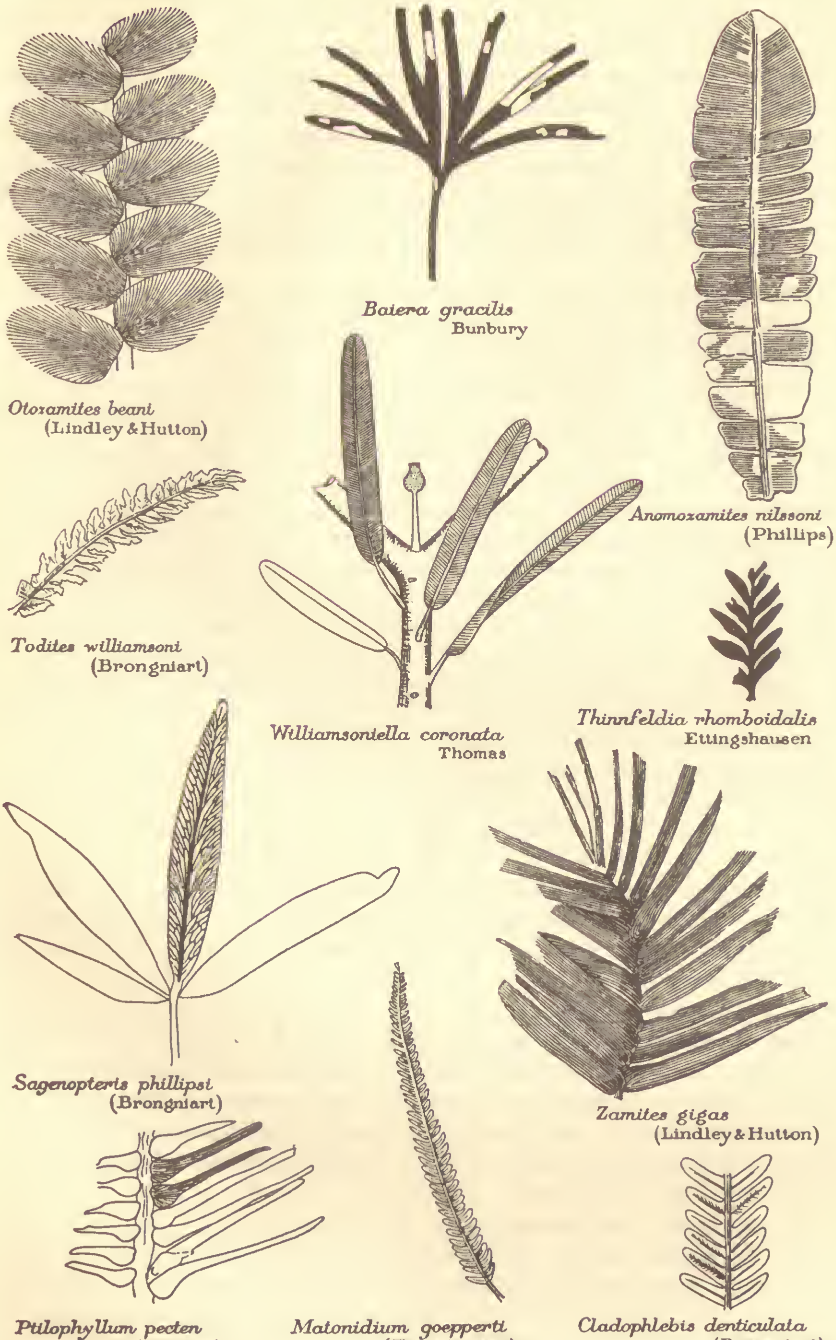


FIG. 13.—*Fossil Plants of the Estuarine Series in Yorkshire.*

into the Dogger and even into the underlying Alum Shale, as for example, on the shore just east of Whitby and also in the alum quarries at Peak, Boulby and Loftus. A similar channelling, but on a greater scale, occurs at the same horizon in the western escarpment of the Cleveland Hills. Plant-beds accompanying, or closely following this period of channel erosion are seen at several localities in the Cleveland Escarpment, and near Whitby, and have yielded a distinctive series of Bennettitalean inflorescences along with such Bennettitalean fronds as *Zamites gigas* (Lindley and Hutton), *Ptilophyllum pecten* (Phillips), and *Otazamites parallelus* (Phillips) and a few ferns. Farther south, at Hayburn Wyke, ferns predominate in the flora.

Middle Estuarine Series.—Along the coast, the bedding of this series is much more regular than that of the other Estuarine beds, and erosion channelling infrequent.

Inland, north of the Market Weighton axis, the series is 20 ft. thick in the Derwent Valley, thickening to 60 ft. at the west end of the Howardian Hills and reaching a maximum of 100 ft. in Cleveland. On the coast these beds show a more rapid thickening northward from 40 to 50 ft. at Gristhorpe to 90 to 100 ft. at Cloughton and Blea Wyke. At Gristhorpe and Cloughton the series contains important plant-beds, from the study of which Dr. H. Hamshaw Thomas has shown that the plants grew almost on the exact spot where their fossilized remains are now found. Although this flora is an extremely rich one, remains of individual species have an extraordinary local distribution; a species may predominate at one place, but be absent a few yards away. This is entirely different from the distribution of fossils in the drifted plant-beds of the Upper Estuarine Series, in which one bedding plane may be strewn with the remains of a few species more or less evenly over a considerable area. The Middle Estuarine flora consists principally of Bennettitales, Ginkgoales, Conifers and Ferns, together with a few Pteridophytes. The most interesting members are the Caytoniales, first discovered by Dr. H. Hamshaw Thomas at Gristhorpe, and since found at widely separated localities in Europe and Greenland. The Yorkshire species, *Caytania sewardi* Thomas and *Gristhorpia natharsti* Thomas, are the earliest known plants bearing closed or angiospermous fruits in Great Britain, and they show distinct evidence of a Pteridosperm ancestry.

Upper Estuarine Series.—The lower part of the Upper Estuarine Series consists of current-bedded sandstones and shales. At the bottom is the Moor Grit—a strongly current-bedded quartzite with abundant casts of logs and branches but no well-preserved plant remains. The sandstones and shales above it contain lenses of silt and sandy shale enclosing a few fossil plants, chiefly Ferns and occasional twigs of Conifers, all well preserved though very fragmentary.

The upper part of the Series is made up of level-bedded shales and fine-grained sandstones. In the Burniston and Scalby coast section the bedding planes of the fissile, micaceous shales are covered with leaves of Ginkgoales, pinnules of Ferns, twigs and cone scales of Conifers, mixed with seeds and other drifted debris. No Cycads are known from these beds, and the flora is characterized by the abundance of Ginkgoales. It is interesting to find that several species, which are found nowhere else in the Middle Jurassic of Yorkshire, occur in these drifted plant-beds, and suggest the presence of a somewhat different flora farther upstream. These alien species are all thick-cuticled forms, allied to *Thinnfeldia* and *Stenapteris*. The *Ginkgoites* beds and *Baiera* beds of the coast sections are interesting in so far as they consists of laminated silt or sandstone infilling a distributary channel and crowded with the leaves of a single species, almost to the exclusion of all other plants.

The total thickness of the Series is about 200 to 220 ft. in North Yorksbire, thinning, westwards to 100 ft. in the northern part of the Hambleton Hills, and southward to 125 ft. in the Gristhorpe cliff south of Scarborough. In the Howardian Hills it is thin and, topographically, insignificant.

CORNBRASH

The Cornbrash is a transgressive deposit and in the Midlands and South of England consists of Upper and Lower parts essentially distinct in lithology and fauna. There is a marked palaeontological break between the Lower and Upper Cornbrash involving a complete change of brachiopod and ammonite faunas, so that the division between the Middle and Upper Jurassic of Great Britain is moıe logically drawn in the middle of the Cornbrash than at the top of that formation. The lower part is characterized by the thin, laterally compressed ammonite *Clydaniceras* and the brachiopods, *Cererithyris*, *Kallirhynchia* and *Ornithella*; while restricted to the upper beds is the inflated, plainly-ribbed ammonite *Macracephalites* and the brachiopods *Microthyridina* and *Rhynchonellaidella*.

The brachiopods have provided the most ready means of subdividing the Cornbrash, and the following four zones have been established:—

Upper Cornbrash	4. *Microthyridina lagenalis*
	3. *Microthyridina siddingtonensis*
Lower Cornbrash	2. *Obovothyris obovata*
	1. *Cererithyris intermedia*

Besides the characteristic ammonites and brachiopods, various lamellibranchs are common and of diagnostic value. In the Lower Cornbrash, *Trigonia angulata* J. de C. Sowerby, *T. rolandi* Lycett, *Astarte hilpertonensis* Lycett, and *Meleagrinella echinata* (W. Smith) are characteristic forms, while the following are restricted to the Upper Cornbrash:—*Trigonia scarburgensis* Lycett, *T. cassiape* d'Orbigny, *Lapha marshii* (J. Sowerby), *Liastrea undosa* (Phillips) and *Lima rigidula* (Phillips).

No record of the Lower Cornbrash is known from South Lincolnshire, but it is well developed at Sudbrooke, north of Lincoln, and persists northward almost to the Humber. Most of the outcrops in Lincolnshire are of the Upper Cornbrash which generally consists of three beds totalling 6 ft. The bottom bed, 2½ ft. thick, is a tough, grey centred, barren limestone, over which is a 2-ft. layer of yellow sandy marl crowded with perfect specimens of the oysters *Lopha marshii* (J. Sowerby) and *Liastrea undasa* (Phillips) along with the rare brachiopod, *Tegulithyris bentleyi* (Davidson), which is restricted to this locality. The top 1½-ft. bed is a hard purplish grey flaggy limestone with *Microthyridina siddingtanensis* (Walker) and *M. sublagenalis* (Davidson).

In the neighbourhood of Lincoln the Lower Cornbrash is represented by 1 ft. of hard blue-hearted shelly limestone with such characteristic fossils as *Obovothyris obovata* (J. Sowerby), *Cererithyris intermedia* (J. Sowerby), *Kallirhynchia yaxleyensis* (Davidson), *Clydoniceras legayi* (Rigaux and Sauvage) and many others. The Upper Cornbrash with its typical fauna is here reduced to 3½ ft., of which the basal 6 in. is marl and rubble and the rest a hard, purplish, flaggy limestone.

The thickness decreases to 3 ft. in north Lincolnshire where exposures are few; this reduction in thickness is continued beneath the Humber and the Cornbrash disappears altogether over the Market Weighton axis, and does not reappear in north-east Yorkshire until the valley of the Rye is reached. Its presence has also been reported at a point on the western escarpment of the Hambleton Hills above Kepwick. During the greater part of the Middle Jurassic period in Yorkshire extensive deltaic conditions held sway, but these were interrupted by marine transgressions of short duration until the final Callovian inundation when there were deposited a few feet of beds classed on their faunal content as of Upper Cornbrash age.

East of Bilsdale the Cornbrash has been traced as a continuous bed under the Kellaways Rock across the Yorkshire Moors, where it is thickest, 5 ft., in Newtondale, to the coast where it thins to 2¾ ft. at Scarborough and 1 ft. at Filey. In Newtondale it is made up of an upper black shelly limestone and a lower hard shelly reddish purple limestone; both contain only Upper Cornbrash fossils.

The lower bed persists eastward to the coast where it is a dark grey gritty limestone capped by a few inches of dark grey mottled marl crowded with crushed specimens of *Microthyridina lagenalis* (Schlotheim).

Upper Jurassic

Lincolnshire

Throughout the Midlands and Lincolnshire the Upper Jurassic is represented by about 600 ft. of argillaceous beds, the Oxford, Ampthill and Kimmeridge clays, with a few feet of sandy Kellaways Beds at the base. The clays are thickest in mid-Lincolnshire and their attenuation northward increases as the Market Weighton axis is approached.

Kellaways Beds.—In Lincolnshire the Cornbrash is succeeded by 2 to 20 ft. of sandy clays which may locally be consolidated into ' rock '. Above these clays lies a 2-ft. bed of calcareous, blue-hearted sandstone with tbe characteristic Kellaways Rock oyster, *Gryphaea bilobata* J. Sowerby and certain belemnites. This sandy facies persists through Lincolnshire and across the Humber to within 4 miles of Market Weighton, where the beds disappear beneath the Cretaceous. Around Drewton, south of Market Weighton, these beds locally amount to 55 ft. of soft sands which are white and highly micaceous below and brown and ferruginous above. The uppermost 10 ft. are abundantly fossiliferous and have yielded *Gryphaea bilobata* J. Sowerby, *Rhynchonelloidella socialis* (Phillips), *Meleagrinella* and belemnites.

Oxford Clay.—The Oxford Clay, 300 ft. thick, is a dark grey clay, which overlies the sandy Kellaways Beds; it shows only a very gradual decrease in thickness northward to the Humber. Much of its outcrop is masked by Glacial Drift and alluvium, particularly in the Fenland area of south-east Lincolnshire and in the Vale of Ancholme.

Layers and nodules of impure muddy limestone are common and in them fossils are beautifully preserved. Among the ammonites are species of *Kasmaceras*, *Quenstedtoceras*, *Peltaceras* and *Creniceras*; oysters are represented by *Gryphaea dilatata* J. Sowerby while *Aulacathyris bernardina* (d'Orbigny) is a noteworthy brachiopod.

Ampthill Clay.—The typical Corallian formation, which includes much limestone, ends abruptly a few miles east of Oxford and is replaced by a black clay, with gypsum and selenite, which is traceable northward as far as the Market Weighton axis. The full thickness of this Ampthill Clay is about 200 ft., but only 17 ft. of this thickness have been seen in an exposure some 13 miles east of Lincoln. There, it has yielded various non-pyritized Corallian ammonites together with *Gryphaea dilatata* J. Sowerby, *Ostrea delta* Smith, *Chlamys fibrosa* (J. Sowerby) and *Pachyteuthis abbreviata* (Miller), all typical of various horizons in the Corallian.

Kimmeridge Clay.—The Ampthill Clay is succeeded by the dark grey Kimmeridge Clay which amounts to about 320 ft. in south Lincolnshire but disappears across the Humber. The majority of the exposures are in the Lower Kimmeridge Clay which usually consists of dark clays with cement-stone bands. The basement beds are generally crowded with the oyster *Ostrea delta* Smith, while the clays above contain beautifully preserved specimens of the ammonite *Rasenia*, notably around Market Rasen, from which locality the generic name is derived; higher beds yield the ammonite *Aulacostephanus*, in which the ribs are interrupted on the periphery, and still higher beds of clays and bituminous shales contain species of the ammonite *Subplanites*. The highest beds so far proved in Lincolnshire occur at Fulletby where they have yielded the zonal ammonite *Virgatasphinctaides* along with the brachiopod *Orbiculoidea* and the bivalve *Lucina*. The upper zones of the Kimmeridge Clay have not been proved owing to lack of exposures and the fact that the fossils are frequently badly crushed; but there is little doubt that the full sequence was originally laid down, since the basal nodular band of the unconformably overlying Spilsby Sandstone contains phosphatized specimens of the ammonite *Pavlavia* derived by erosion from the top beds of the Kimmeridge Clay. No Jurassic strata of later date than the Kimmeridge Clay, such as the Portland and Purbeck Beds of the South of England, occur in Lincolnshire and Yorkshire.

Yarkshire

In Yorkshire, the sequence of Upper Jurassic rocks comprises sandstones, clays, and limestones, made up as follows:

		Ft.
Kimmeridge Clay	.. ..	0 – 400
Corallian Series	Upper Calcareous Grit ..	30 – 80
	Osmington Oolite Series ..	50 – 90
	Middle Calcareous Grit ..	0 – 80
	Hambleton Oolite Series ..	0 – 120
	Lower Calcareous Grit ..	70 – 200
Oxford Clay ..	.. ..	0 – 130
Hackness Rock ..	.. ..	6 – 25
Kellaways Rock	.. ..	50 – 90

Kellaways Rock.—The Kellaways Rock usually consists of shales below with thick soft sandstones above. On the coast, it first appears above the

Cornbrash in Newbiggin Wyke, north of Filey Brigg, and is traceable northward through the cliffs around Gristhorpe Bay to Red Cliff where it comprises 20 ft. of hard and soft sandstones over 15 ft. of shales. These beds have yielded the fauna of the Koenigi Zone. The Kellaways Rock is again seen at Osgodby Nab and below Scarborough Castle Hill where it is 51 ft. of thickly-bedded barren sandstone. From Cayton Bay the outcrop strikes inland through the Hackness, Tabular and Hambleton hills where it gives rise to easily discernible rounded buttresses or nahs below the dissected Lower Calcareous Grit escarpment. In the precipitous sides of Newtondale there are 120 to 130 ft. of massive hard and soft sandstones with shales at the base, of which the upper 30 to 50 ft. are probably referable to the Hackness Rock, while the rest is included in the Kellaways Rock. The latter is occasionally exposed along the western flank of the Hambleton Hills and at the foot of Boltby Scar about 50 ft. of hard and soft sandstones are visible, the topmost bed being capped by a layer of *Gryphaea bilobata* J. Sowerby, with Oxford Clay shales above. Similar beds occur farther south at Whitestone Cliff, and at Roulston Scar the so-called Kellaways Rock is subjacent to the Lower Calcareous Grit. It is not known to what extent the upper beds of this Kellaways Rock may represent an arenaceous development of the Oxford Clay, which otherwise is absent at this locality (Fig. 14).

Outliers of Kellaways Rock occur on Harwood Dale and Fylingdales Moors and in north Cleveland to the north of Eskdale. In these areas hard siliceous sandstones with abundant casts of belemnites form the upper part, while the lower part is flaggy and contains quartz pebbles except towards the base where the beds are shaly. In the Howardian Hills, the Kellaways Rock is represented by 30 to 40 ft. of yellow sands with occasional streaks and nodules of ironstone. Near Malton these sands are suitable for glass making. South-east of the Derwent exposures are sporadic and it gradually thins out towards the Market Weighton axis. South of that axis loose micaceous sands occur at Newbald and Drewton and have yielded the fauna characteristic of the Koenigi and Calloviense Zones.

Hackness Rock and Oxford Clay.—Elsewhere in England the Kellaways Rock is usually succeeded by the thick clay series known as the Oxford Clay, but in Yorkshire this series consists of lower arenaceous beds—the Hackness Rock—overlain by grey shales extending up to the top of the Mariae Zone. In the cliffs between Filey and Scarborough the Kellaways Rock is followed in turn by 19 ft. of Hackness Rock, and about 130 ft. of Oxford Clay which, in the upper part of the cliffs, passes up into the Lower Calcareous Grit.

There is a non-sequence at the base of the Hackness Rock, the Jason and Coronatum Zones and probably also the upper part of the Calloviense Zone are absent, though the precise extent of this gap is, however, unknown.

At Scarborough Castle Hill the Hackness Rock has increased to 25 ft., while the overlying shales are only a few feet less than at Gristhorpe Bay.

Inland, little is known of the Hackness Rock, but the shales and clays above it form a belt of wet ground beneath the Lower Calcareous Grit escarpments from the coast westward to the Hambleton Hills, where their thickness has diminished to 50 ft. below Black Hambleton; farther south they thin out altogether at Roulston Scar (Fig. 14). The lowest few feet of

A.—CURRENT BEDDING IN ESTUARINE SERIES AT SPION KOP, WHITBY

B.—LINCOLNSHIRE LIMESTONE OVERLYING NORTHAMPTON IRONSTONE AT GREETWELL, NEAR LINCOLN

[*To face page* 44

A.—CLIFFS OF CORALLIAN BEDS OVERLAIN BY BOULDER CLAY ON THE NORTH SIDE OF FILEY BRIGG

B.—KELLAWAYS ROCK, HACKNESS ROCK AND OXFORD CLAY CAPPED BY LOWER CALCAREOUS GRIT AT HIGH RED CLIFF, CAYTON BAY, NEAR SCARBOROUGH

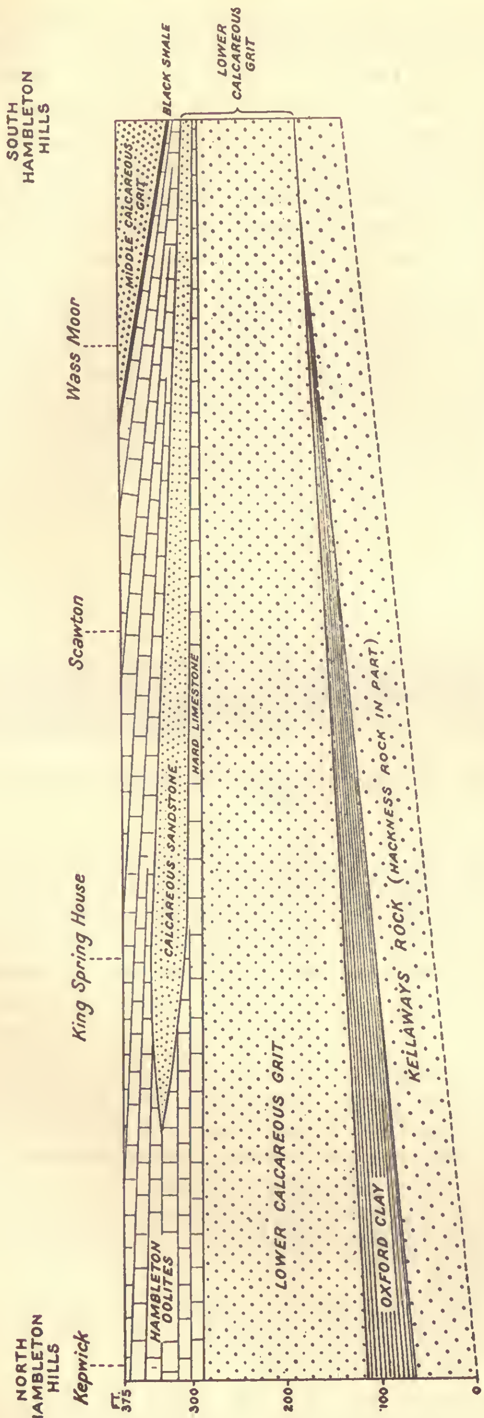


FIG. 14.—*Diagrammatic section showing the variations in thickness of the Upper Jurassic rocks in the Hambleton Hills*

these shales at Boltby Scar have yielded ammonites of the Lamberti Zone. In the Howardian Hills outcrops of the Oxford Clay are sporadic owing to the faulted nature of the area; it is about 60 to 70 ft. thick and at High Hutton ammonites common in the Lamberti Zone have been obtained.

South-east of the Derwent, Oxford Clay forms occasional low banks at the foot of the Wolds and is less than 20 ft. at Garrowby beyond which it disappears completely towards the Market Weighton axis. About 50 ft. of Oxford Clay occurs to the south of that axis, and the basal portion has yielded ammonites belonging to the Jason Zone. While the Kellaways Rock and Oxford Clay are remarkably unfossiliferous, the Hackness Rock has yielded abundant fossils. From the lower part, in particular, species of the ammonites *Kosmosceras*, *Cadoceras*, *Peltoceras*, and *Proplanulites koenigi* (J. Sowerby) and many Gryphaeas have been recorded on the coast. From the fossils it appears that the Kellaways Rock of the coast represents the lower part of the Kellways Beds of the rest of England, while the overlying Hackness Rock is equivalent to the Lower and Middle Oxford Clay, and that the whole of the Yorkshire Oxford Clay ranges from the Coronatum Zone to the Mariae Zone.

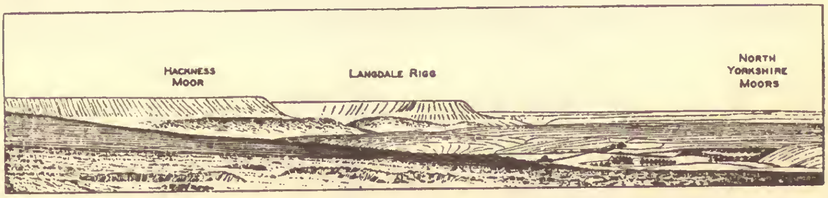


FIG. 15.—*Harwood Dale and the north-facing Corallian escarpment of the Tabular Hills.*

The Corallian Series.—The argillaceous conditions of the Oxford Clay were terminated by an influx of fine arenaceous material which marks the beginning of the Lower Calcareous Grit, the lowest member of the Corallian Series. The great spread of these rocks, made up of many hundreds of feet of sandstones and oolitic limestones, may be conveniently divided into the three topographic areas of the Tabular, Hambleton and Howardian hills.

In the Tabular and Hambleton hills areas the strike is generally east and west, with a low dip to the south. The harder beds tend to weather out as plateaux increasing in height from the coast westward to Black Hambleton (1,300 ft. O.D.). The plateaux are terminated by steep banks or even precipices in a remarkable line of escarpments facing the Cleveland Hills (Fig. 4 and 15), broken only by the numerous rivers and streams which flow southward through steep-sided gorges (Forge Valley, Newtondale, Ryedale, &c.) into the Vale of Pickering.

Intense faulting complicates the stratigraphy in the Howardian Hills and the strike of the beds is approximately E.S.E.–W.N.W. with varying degrees of dip to the N.N.E.

Well-defined fault-scarps occur on the north and south sides of the Coxwold-Gilling Gap, but the Gilling escarpment becomes less marked towards Hovingham.

Immediately to the south of Malton the Langton-Settrington ridge constitutes a lesser east and west escarpment by reason of a fault along its northern flank.

The 'grit' subdivisions of the Corallian are neither true grits nor true limestones, but may be referred to as fine-grained calcareous gritstones. Variations in lithology occur in both gritstones and oolites, but are most marked in the latter, with which facies reefs are also associated. Changes in the nature and profusion of the faunas are also more pronounced in the oolitic episodes.

Lower Calcareous Grit.—The outcrop of these fine-grained grits extends from the coast at Filey Brigg through the Hackness and Tabular hills to the western escarpment of the Hambleton Hills; thence it swings south-eastward, is broken by the Coxwold—Gilling Gap and continues through the Howardian Hills to the foot of the Chalk Wolds. These gritstones are the foundations of Filey Brigg and gradually rise from their position below sea level until they constitute the fine cliffs between the Brigg and Gristhorpe Bay. Inland, this grit plays the dominant role in a series of abrupt escarpments backing the Tabular and Hambleton hills to the north.

A gradual passage from the Oxford Clay to the Lower Calcareous Grit is apparent throughout Yorkshire except in the south-west part of the Hambleton Hills where, at Roulston Scar, the gritstone lies directly on the Hackness Rock, the Oxford Clay being absent (Fig. 14, p. 45).

The Lower Calcareous Grit has its maximum development in the Tabular and Hambleton hills and thins out towards the Market Weighton axis in the south and to a lesser extent towards the east, particularly from the Hackness Hills to the coast where the diminuntion in thickness amounts to 75 ft. in 6 miles. It has been shown how the Peak Fault, in this coastal area, was moving during the deposition of the Blea Wyke Beds and the Dogger, and it is suggested that some movement along this line of weakness farther south may have taken place in post-Oxford Clay times and produced this easterly thinning in the Lower Calcareous Grit.

Coast sections in the Lower Calcareous Grit show the following details:—

	Ft.
3. 'The Ball Beds'; incoherent, very ferruginous sandstone containing large gritty, fossiliferous limestone doggers	10 – 18
2. Hard, grey, siliceous grit	3 – 7
1. Thickly bedded, hard, buff gritstone with a siliceous cement frequently concentrated into small masses which weather out in irregular nodular bands	40 – 45

These beds are recognized throughout the outcrop westward to Ryedale, but in the escarpments north of Kirby Moorside and Helmsley the Grit becomes intensely siliceous, owing to the abundance of the siliceous spicules of the sponge *Rhaxella perforata* Hinde, and chert bands are frequent. In the Howardian Hills the 'Ball Beds' are not developed; the Grit varies from a hard siliceous spicule-bearing rock in the west to gritty limestone-centred beds and soft sandstones in the south-east.

Fossils are not common in the Lower Calcareous Grit, but fine specimens of the ammonites *Aspidoceras* and *Cardioceras* have been obtained together with the small brachiopod *Thurmannella thurmanni* (Voltz), the oysters *Exogyra nana* (J. Sowerby) and *Gryphaea dilatata* J. Sowerby, other lamellibranchs such as *Chlamys fibrosa* (J. Sowerby), *Trigonia triquetra* Seebach and *Modiolus bipartitus* (J. Sowerby), and the sea-urchins *Nucleolites scutatus* Lamarck and *Collyrites bicordata* (Leske).

Hambleton Oolite Series.—This series consists mainly of oolitic limestones which in the Hackness Hills and coast sections exhibit considerable variation in lithology and fauna.* The whole series is lenticular, being thickest about Kirby Moorside, and is confined to the Tabular and Hambleton hills, there being no certain representative of it in the Howardian Hills. In the Filey district the conjunction of irregular hard bands with equally uneven intercalated sandy partings in the lower beds is considered to indicate intermittent intraformational erosion during deposition. The series amounts to 28 ft. at Filey Brigg, but increases to about 54 ft. at Scarborough Castle Hill, where the upper 26 ft. are oolitic limestones and the rest variable sandstones and harder detrital limestones.

FIG. 16.—*Fossil Sponges from the Corallian (Hambleton Oolite) of Hackness.* (All natural size)

A. *Corynella chadwicki* Hinde.
B. *Holcospongia floriceps* (Phillips).
C. *Holcospongia polita* Hinde.

In the Hackness Hills the upper 30 ft. are of oolite resting on 11 ft. of the unique Coral-Sponge Rag, the latter consisting of an intimate mixture of masses of compound coral and sponges along with a profuse associated fauna in a matrix of reef detritus and fine mud. The most abundant fossils from the numerous quarries in this deposit include the sponges, *Holcospongia floriceps* (Phillips), *H. polita* Hinde, *Peronidella recta* Hinde; the corals *Thamnasteria concinna* (Goldfuss), *Isastraea explanata* (Goldfuss), *Rhabdophyllia phillipsi* Edwards and Haime; numerous Terebratulids, Cidarid spines and many mollusca, such as *Chlamys fibrosa* (J. Sowerby), *Camptonectes lens* (J. Sowerby), *Ostrea quadrangularis* Arkell, *Astarte ovata* Smith and *Pseudomelania heddingtonensis* (J. Sowerby).

Certain of the beds in the Scarborough and Filey sections contain sponges, rolled fragments of *Rhabdophyllia*, Cidarid spines and small Terebratulids and may be correlated with the Coral-Sponge Rag of Hackness. Another noticeable feature of these beds along the coast is the profusion of oysters and annelid incrustations, indicating shallow water conditions.

* These beds attracted much attention from William Smith, the 'Father of English Geology', who lived at Hackness from 1828–1834.

Westward from the Hackness Hills, the Hambleton Oolites thicken, become somewhat siliceous and chert centres are often developed in individual beds. These siliceous beds invariably contain spicules of *Rhaxella perforata* Hinde indicating that this sponge persisted for some time in western districts after the close of the Lower Calcareous Grit episode. Usually the oolites are poorly fossiliferous but occasional local shelly bands, as at Wydale Thorntondale and Newtondale, have yielded many fossils.

Middle Calcareous Grit.—Sandstones, gritty limestones and impure oolites comprise this subdivision which is absent in the Howardian Hills. In the Hambleton and Tabular hills its thickness varies from 15 to 60 ft. With the exception of the rich *Trigonia hudlestoni* Beds at Pickering, the fauna as a whole is scanty and poorly preserved. Sandstones and gritty limestones of this age constitute a large part of Filey Brigg and in them the following fossils are common:—*Gervillia aviculoides* (J. Sowerby), *Trigonia hudlestoni* Lycett, *Pseudomonotis ovalis* (Phillips), *Chlamys fibrosa* (J. Sowerby), *Pseudomelania heddingtonensis* (J. Sowerby), and spicules of *Rhaxella perforata* Hinde.

The maximum thickness, about 60 ft., of the Middle Calcareous Grit occurs to the south-west of the River Rye, at Helmsley; eastward this thickness diminishes to 40 ft. of gritty limestones and local shell beds—the *Trigonia hudlestoni* Beds—at Pickering, and in Forge Valley, no more than 20 ft. of impure gritty limestones are of this age. The *Trigonia hudlestoni* Beds are thin shell beds in which the following species of the bivalve *Trigonia* predominate—*Trigonia hudlestoni* Lycett, *T. reticulata* Agassiz and *T. pickeringensis* Arkell together with *Gervillia aviculoides* (J. Sowerby), *Cucullaea contracta* Phillips, *Opis curvirostra* (Smith), *Placunopsis radiata* (Phillips), *Lopha gregarea* (J. Sowerby), *Procerithium muricatum* (J. Sowerby), *Nerinea visurgis* Roemer and *Pseudomelania heddingtonensis* (J. Sowerby). Occasional lumps of the coral *Thamnasteria arachnoides* (Parkinson) are often seen in the impure oolites associated with these shell beds.

Osmington Oolite Series.—The deposits included in this series occur in all three of the topographic Corallian regions in Yorkshire and they extend round the fringe of the Vale of Pickering to the foot of the Chalk Wolds. They average 60 ft. in thickness and consist of dominantly pure, unfossiliferous oolites, overlain by a variety of beds collectively known as the Coral Rag.

The series is well developed along the southern flank of the Tabular Hills from the coast to Ryedale, and is responsible for the Cauklass Promontory extending into the western end of the Vale of Pickering. It is again well developed in the Howardian Hills, commencing in the plateau to the east of Gilling; its continuity to North Grimston at the foot of the Chalk escarpment, where it is nearly 90 ft. thick, is only broken by intense faulting.

Coral reefs were extensive during the latter part of Osmington Oolite times, the compound corals *Isastraea* and *Thamnasteria* together with the simple forms *Thecosmilia* and *Montlivaltia* being mainly responsible. In the interstices of the reefs occur the lamellibranchs *Lima zonata* Arkell, *Chlamys nattheimensis* (de Loriol), *Lithophaga inclusa* (Phillips), *Lopha gregarea* (J. Sowerby) and the small gastropod *Littorina muricata* (J. Sowerby), together with the spines of *Paracidaris smithi* (Wright) and *P. florigemma* (Phillips).

In tbe Forge Valley area the Coral Rag is represented by a massive Thamnastraean reef, 22 ft. thick, whicb was cut through, locally, by a channel into whicb reef detritus was swept and in which lived a fauna quite distinct from tbat inbabiting the reef. Among the fossils occurring in tbe cbannel deposit are the gastropods *Bourguetia striata* (J. Sowerby) (very large and abundant), *Pseudomelania heddingtonensis* (J. Sowerby), *Trochotoma tornatilis* (Phillips), *Nerinea visurgis* Roemer, *Natica arguta* Phillips, together with *Hemicidaris intermedia* (Fleming), *Paracidaris smithi* (Wright), large numbers of tbe small '*Terebratula*' *kingsdownensis* Arkell, *Navicula quadrisulcata* (J. de C. Sowerby) and many other lamellibranchs.

West of Tborntondale tbe lowest 9 to 13 ft. of the series are impure oolites witb sbell beds and occasional nests of corals; tben come 18 to 20 ft. of shelly oolites—tbe *Pseudomelania* Limestones—and about 15 ft. of earthy and detrital limestones—the Pickering Limestones, capped by a single hard bed of claystone—the ' Throstle '.

West of Pickering the Coral Rag is characterized by the corals *Thecosmilia annularis* (Fleming), *Montlivaltia dispar* (Phillips) and *Rhabdophyllia phillipsi* Edwards and Haime along with the usual reef-dwelling mollusca and other fossils; it seems probable that unstable coral banks rather than true reefs existed hereabouts.

In the south Hambleton Hills the Coral Rag, underlain by about 40 ft. of oolites, extends from Oswaldkirk tbrough the Cauklass Promontory and is identical in character with that around Sinnington and Kirby Moorside. Locally, between Helmsely and Sproxton, the Coral Rag is represented by a fine-grained argillaceous limestone containing stray reef fossils and occasional lumps of dark chert.

In the Howardian Hills the Coral Rag occurs above shelly and oolitic limestones, which, in the vicinities of Appleton-le-Street and North Grimston are represented by the impure marly ' Urchin Dirt Beds ' which carry large numbers of *Nucleolites scutatus* Lamarck. The Rag is well developed around Gilling, Hovingham, Slingsby, Malton and North Grimston; at the last-named locality it contains much nodular chert.

At Hildenley, neaı Malton, there is a faulted mass of pure white limestone with stray reef fossils; this represents fine calcareous mud washed from some nearby reef now no longer visible.

Upper Calcareous Grit.—At the close of the Osmington Oolite period of sedimentation conditions again became sufficiently arenaceous to be inimical to the continuance of coral growth, for the succeeding deposits are the 46 ft. of well-bcdded buff gritstones known as Upper Calcareous Grit. In the meantime, however, submarine erosion has levelled out the banks and reefs of the Coral Rag and it is evident that in this process the detritus, along with the finer incoming arenaceous material, was washed southward over the site of the Howardian Hills. The outcrop of the Upper Calcareous Grit is limited; it forms an intermittent cap to some of the southern ridges of the Tabular Hills, but is continuous from Pickering westward through Helmsley into the south-east part of the Hambleton Hills and the Cauklass Promontory. Throughout the whole of this area it is a fine-grained gritstone resting on a variable thickness (10 ft. at Pickering) of sandy shales, and though an impoverished fauna is to be expected, the lamellibranchs *Gryphaea* *dilatata* J. Sowerby, *Lucina fulva* Arkell, *Chlamys fibrosa* (J. Sowerby), *C. midas* (d'Orbigny) and *Camptonectes lens* (J. Sowerby) and fragments of ammonites are fairly common. There are excellent sections in these beds at Pickering, in Hutton Beck and in the Nunnington railway cutting.

In the Howardian Hills, rocks of this age occur at two localities; at Snape Hill, near Kilburn the sequence comprises 48 ft. of alternating hard and soft beds of fine calcareous mudstone which become more arenaceous in the upper 12 ft.

Similar beds occur between Langton and North Grimston where they are known as the ' North Grimston Cementstones '; about 36 ft. are visible but Fox-Strangways estimated the full thickness at about 80 ft. They have yielded large numbers of the oyster *Gryphaea dilatata* J. Sowerby, together with *Gervillia sulcata* Étallon, *Pholadomya hemicardia* Roemer, *Exogyra nana* (J. Sowerby) and fragments of belemnites and ammonites.

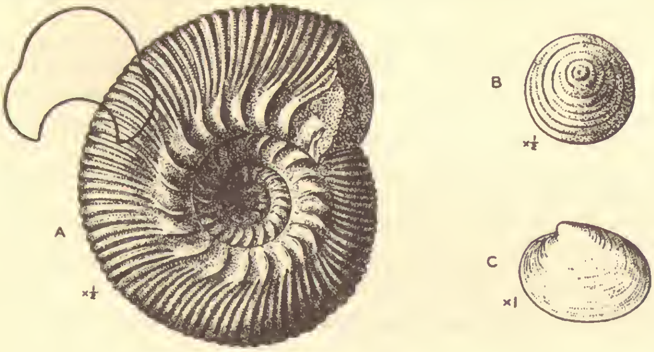


FIG. 17.—*Kimmeridge Clay Fossils.*

A. *Rasenia uralensis* (d'Orbigny).
B. *Discina latissima* (J. de C. Sowerby).
C. *Lucina minuscula* Blake.

Formerly it was thought that the Kimmeridge Clay lay unconformably on these cementstones, but it has since been shown that there is a gradual passage between the two.

Kimmeridge Clay.—The Kimmeridge Clay underlies the broad Vale of Pickering, upwards of 400 ft. of poorly fossiliferous shales and clays being present beneath the alluvial deposits while isolated patches of the clay resting on the Upper Calcareous Grit border the alluvium along the northern fringe of the Vale. The lowest part consists of brown, grey and mottled shales with *Ostrea delta* Smith, *Exogyra nana* (J. Sowerby) and *Serpulae* and is followed by black shales and clays.

There are isolated outcrops of Kimmeridge Clay in the Howardian Hills near Malton, Birdsall and North Grimston where fossils indicate the presence of the Rasenia Zone. Southward towards the Market Weighton axis it diminishes in thickness and disappears altogether between Acklam and Kirby Underdale; nor does it reappear north of the Humber.

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VI. THE CRETACEOUS SYSTEM

IN THE CLOSING ages of the Jurassic Period the retreat of the sea had proceeded so far that the greater part of Britain became land; in fact, no trace of Jurassic deposits of post-Kimmeridgian age has been found in Lincolnshire and East Yorkshire. After a considerable interval, our area was invaded from the east by the advancing waters of the early Cretaceous sea, and a series of sands, clays, limestones and ironstones was laid down unconformably on the eroded surface of the Kimmeridge Clay in Lincolnshire, while at Speeton, on the Yorkshire coast, a considerable thickness of clays accumulated under quiet marine conditions. At the close of Lower Cretaceous time there was a further general reduction of the surrounding land areas, and the sea in which the Chalk was deposited spread far and wide.

Lower Cretaceous

Lincolnshire

Lower Cretaceous strata cover much of Lincolnshire; around Spilsby at the southern end of the Wolds, their outcrop is nearly 6 miles wide and it extends northward with diminishing width for a distance of about 30 miles before finally disappearing in the vicinity of Elsham. Throughout this tract the series rests unconformably on the Kimmeridge Clay; it is thickest and most fully developed in the south where Professor H. H. Swinnerton has recently established the following succession:

			Ft.
Langton Series		Red Chalk	24
		Carstone Grit	10
		Carstone Sands and Clays	14
		Sutterby Marl	11
Tealby Series	Fulletby Beds	Upper Roach	9
		Roach Stone	18
		Lower Roach	25
	Tealby Beds	Upper Tealby Clay	37
		Tealby Limestone	13
		Lower Tealby Clay	42
	Claxby Beds	Upper Claxby Ironstone	
		Hundleby Clay	24
		Lower Claxby Ironstone	
Spilsby Series	Spilsby Sandstone	Ferruginous Grit	3
		Glauconitic Sands	70
		Basement Beds	3

Spilsby Sandstone.—In the lowest 3 ft. of the Spilsby Sandstone there are large numbers of phosphatic nodules, decreasing upwards in numbers and size, which contain derived Portlandian ammonites and other fossils of boreal types, bored by the lamellibranch *Martesia*. At the base is a thin layer of blue clay riddled with worm borings infilled with white sand. Generally, the sandstone comprises soft greenish yellow sands and light grey clay with widely disseminated glauconite. In some places it is brown and ferruginous and often contains sandy phosphatic nodules. Larger concretions

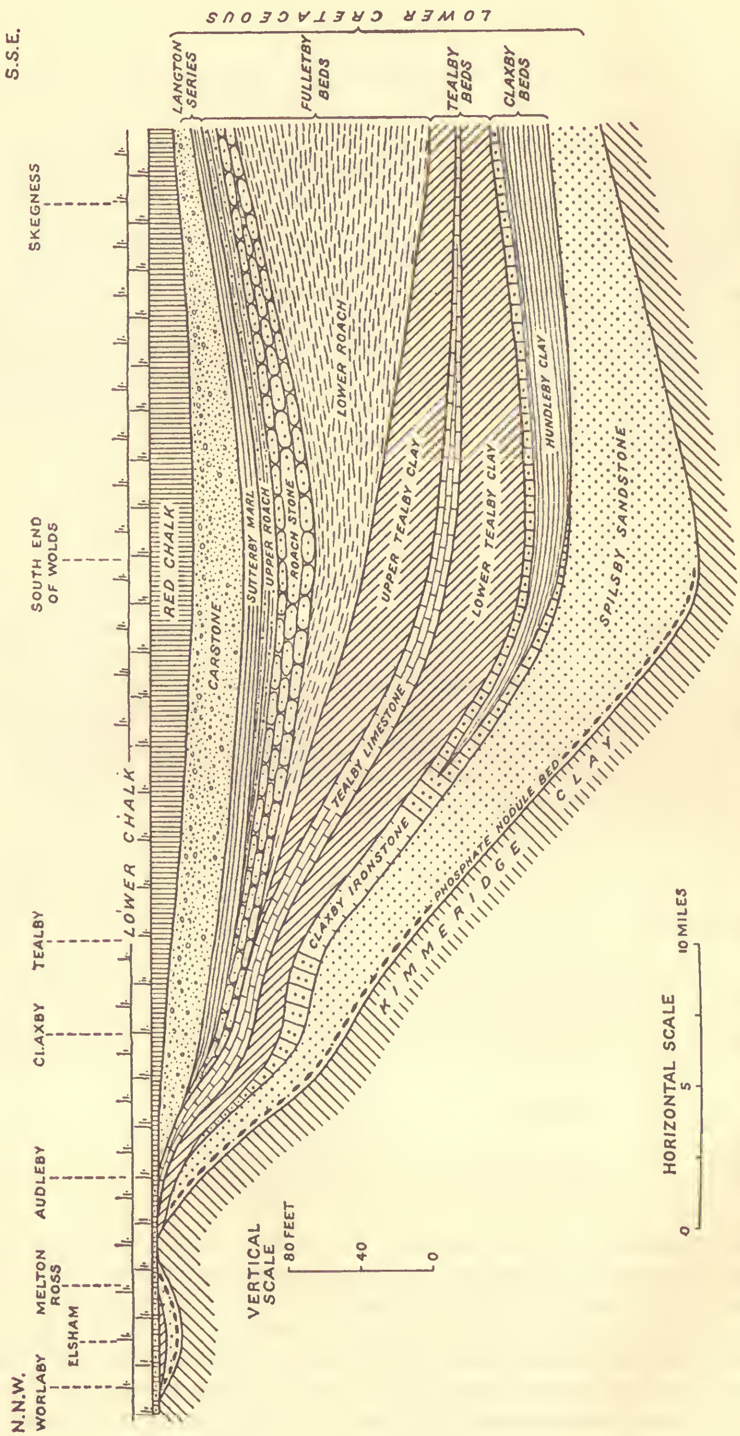

FIG. 18.—*Diagram showing the variations in thickness and lithology of the Lower Cretaceous rocks of Lincolnshire.*

of hard calcareous sandstone are not infrequent. Among the fossils it yields are:—*Acroteuthis laterolis* (Phillips), *A. subquadrotus* (Roemer), *Paracraspedites stenompholoides* Swinnerton, *P. bifurcatus* Swinnerton, *Buchia volgensis* (Lahusen) and other lamellibranchs.

Borings in the vicinity of Skegness have penetrated the Lower Cretaceous beds and here the Spilsby Sandstone is about 20 to 25 ft. thick. In pre-Glacial times its outcrop appears to have formed a broad sandy plateau about 9 miles long and 3 to 4 miles wide at its southern extremity, extending from the base of the Chalk along the south-west flank of the Wolds and terminating westwards in a subsidiary escarpment. It is now partially covered by a mantle of boulder clay but has been deeply excavated by the valley of the Steeping River. The Spilsby Sandstone is about 76 ft. thick at the south end of the Wolds but thins gradually northward to 40 ft. at North Willingham and 25 ft. at Claxby beyond which it thins more rapidly; it is believed to be absent between Clixby and Melton Ross, but reappears as a narrow outcrop between Melton Ross and Elsham before it is finally hidden by the overstep of the Chalk.

Around Spilsby the greenish yellow and white sands are about 20 ft. thick and have yielded *Acroteuthis laterolis* (Phillips), *Entolium orbiculore* (J. Sowerby), *Lucino* and *Subcrospedites plicmopholus* (J. de C. Sowerby). At Audleby the upper part of these sands contains abundant small pebbles of white quartz and black lydian stone. Farther north the sands are coherent and give rise to a prominent bank on the hillsides around Nettleton and Elsham.

Claxby Beds.—These beds are predominantly dark clays, but some are of rich oolitic iron ore.

At Hundleby they are represented by 18 ft. of non-ferruginous clay, the Hundleby Clay, generally purple in colour but tending to become grey, laminated and sandy upwards. North of Hundleby ferruginous bands begin to appear and at Claxby the clay is almost entirely replaced by the Claxby Ironstone; this, in its lower part contains a considerable amount of sand and grit. The ironstone usually gives rise to a well defined outcrop and locally, to the west of Scremby, it forms a broad platform with broad knolls along its southern edge. At Langton, 3 miles north of Spilsby, the ironstone is 12 ft. thick and farther north between Claxby and Nettleton it attains its maximum thickness of 14 ft.; to the north it thins out and disappears a short distance beyond Caistor. The upper part of the ironstone consists of a dark red ferruginous rock, more or less shaly and concretionary, while the lower part comprises greyish red oolitic beds which are worked for iron. Fossils are fairly common in these beds and include *Lyticoceros oxygonium* (Neumayr and Uhlig), *Olcostephonus*, *Dichotomites*, *Exogyra sinuota* (J. Sowerby), *Trigonia ingens* Lycett, *Camptonectes cinctus* (J. Sowerby), *Cucullaea donningtonensis* (Keeping), belemnites of the *laterolis* group, and many brachiopods.

Tealby Beds.—Clays, shales and sandy limestones comprise this group. The Lower Tealby Clay is uniformly grey in colour; it contains widely disseminated glauconite in varying degrees of concentration, and has a layer of phosphatic nodules near the middle. There are occasional erosion surfaces in the lower part and these are usually covered with subangular pebbles of quartzite and eroded fossils bored by sponges and molluscs.

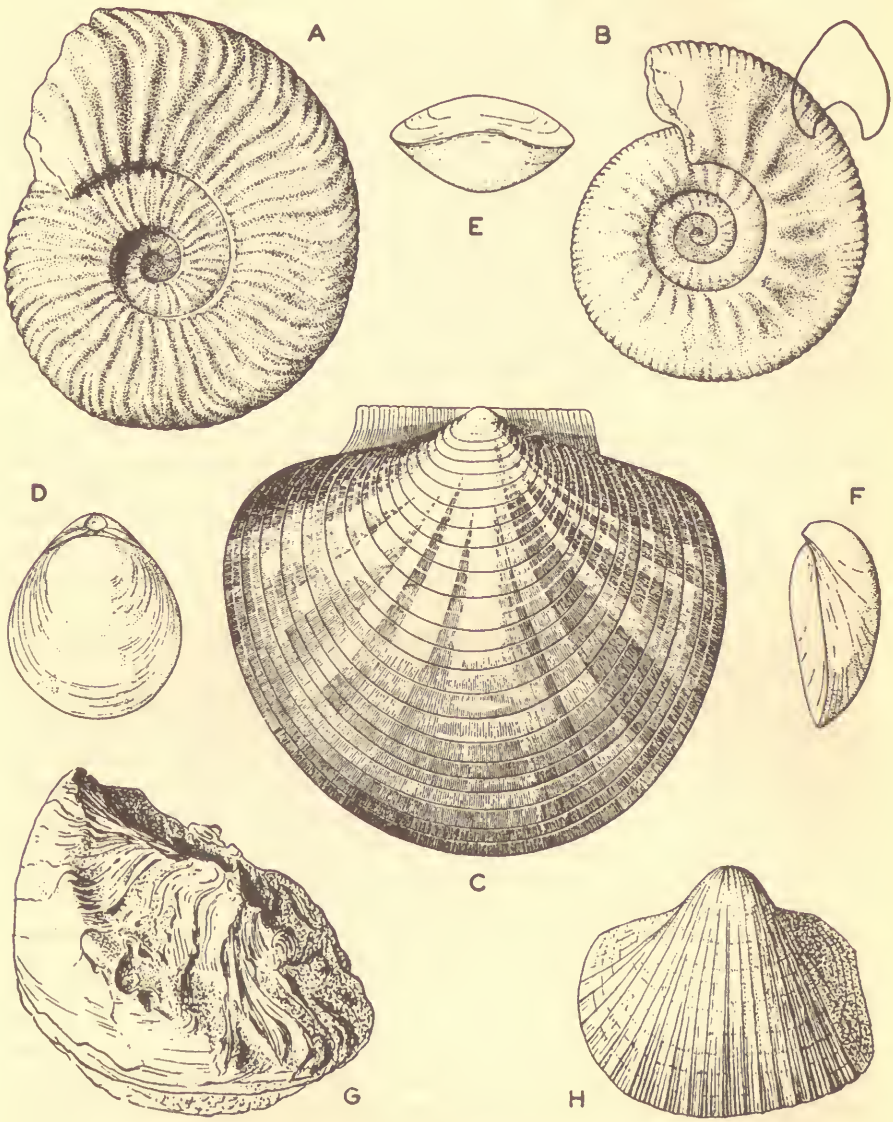

FIG. 19.—*Fossils from the Lower Cretaceous rocks of Lincolnshire*

(D, E, F and H natural size, others half natural size)

A. *Lyticoceras oxygonium* (Neumayr and Uhlig).
B. *Subcraspedites plicomphalus* (J. de C. Sowerby).
C. *Camptonectes cinctus* (J. Sowerby)
D, E and F. '*Zeilleria*' *tamarindus* (J. de C. Sowerby) var. *magna* (Walker).
G. *Exogyra sinuata* (J. Sowerby).
H. *Cucullaea* (*Dicranodonta*) *donningtonensis* Keeping.

The Tealby Limestone is a well-marked horizon of alternating hard and soft sandy limestones, clays and shales, with small quantities of glauconite scattered throughout and, in the bottom beds, pyritous nodules.

The succeeding Upper Tealby Clay is mainly grey and silty, but some of the beds are buff coloured and the lowest layers contain glauconite. The Tealby Beds are not well exposed and fossils are not plentiful; however, *Hibolites jaculum* (Phillips) occurs in the lower clays while *Oxyteuthis brunsvicensis* (Strombeck) is found in the Limestone and also in the upper clays along with *Aulacoteuthis speetonensis* Pavlov and *A. absolutiformis* Sinzow. The ibiquitous shallow water oysters *Ostrea* and *Exogyra* are common throughout.

Fulletby Beds.—The Upper Tealby Clays pass upwards into others varying in colour from grey to black. At some levels these clays are sandy or calcareous and give rise to hard stony bands.

Oolitic iron ore is present throughout and locally may form the whole of the lower beds. In the uppermost 5 ft. some layers are essentially sandstones, to which the term ' Roach Stones ' has been applied, and they contain a smaller quantity of oolitic iron ore than the beds above and below. In the past, considerable uncertainty has existed over the precise field relationships of this Roach Stone and the Tealby Limestone; both give rise to well-defined features over parts of their outcrop, the former in the south, the latter from the vicinity of Donnington northward, but neither is developed in the intervening area. Previous workers have regarded the rocks forming these two features as equivalent but Professor H. H. Swinnerton has shown that they are distinct and referable to different horizons. The Fulletby Beds were originally deposited in thin layers of pure clay and ferruginous clay, but the action of burrowing organisms has resulted in an inextricable mixture. Carbonized plant fragments are fairly common but other fossils are less frequent and limited to certain horizons.

Langton Series.—The lower member of this series, the Sutterby Marl, consists of marl and dark grey clay with patches of pyrites in the lower part. It is confined to that part of the area south of Oxcombe, while to the north, the Carstone Sands and Clays comprise the whole of the series. Fossils in the Sutterby Marl are common and are characteristic of the middle portion of the Lower Aptian; the following are present:—*Neohibolites ewaldi* (Strombeck), *N. spicatus* Swinnerton, *Hibolites minutus* Swinnerton, *Oxyteuthis* aff. *brunsvicensis* (Strombeck), *Deshayesites fissicostatus* (Phillips), and *Aconeceras nisoides* (Sarasin). The Marl becomes sandy upwards and passes via sandy marls and fine sands into coarser sands and grits which form the highest part of the deposit termed ' Carstone '. In addition to sand grains the Carstone contains a variety of other constituents—small pebbles of black lydian stone, fragments of broken shells, oolitic iron ore and occasional grains of glauconite. Fragments of belemnites found in the lower marly glauconitic part of the Carstone show affinity with the *ewaldi* group of the genus *Neohibolites*. In the southern part of the area, the variable deposits included in the Carstone are thickest and the upper part, or ' Carstone Grit ', is coarser than the beds below.

Northward the grit transgresses the Carstone sands and sandy marls, the Sutterby Marl, and the other members of the series, until north of

Audleby, it rests on the Kimmeridge Clay. In the course of this northward transgression the Carstone Grit diminishes in thickness and becomes progressively coarser; between Audleby and Tealby it is exceptionally coarse and contains numerous phosphatic nodules and fragmentary casts of ammonites. Another curious fact is that the Grit maintains a gradual transition into the overlying Red Chalk, into which, in the neighbourhood of Worlaby, it also passes laterally, the lower part of the Red Chalk there being conglomeratic.

The variations in thickness and lithology of the Lower Cretaceous beds described above are diagrammatically represented in Fig. 18. It will be seen that the complete series attains its maximum development of 280 ft. at the south end of the Wolds; rapid thinning takes place northwards while the Skegness borings indicate considerably less thinning to the south-east; these borings, moreover, reveal interesting changes in the relative thicknesses of the different facies.

Yorkshire

The Lower Cretaceous deposits in Lincolnshire become gradually thinner as they approach the Market Weighton Axis, and disappear near Worlaby; no further trace of them is found until 11 miles north of the Humber in Spring Dale just south of the village of Goodmanham, indications of coarse Carstone sands are seen below the Red Chalk.

Similar variegated ferruginous sands occur farther north in Millington Dale, north-east of Millington, and at Great Givendale a band of conglomerate intervenes between these sands and the Red Chalk. At the head of Scottendale, east of Kirby Underdale, the following sequence is exposed:

		Ft.
Red Chalk	Nodular	3
	Soft marly	1
Carstone	Brown marly sand	1
	Coarse ferruginous sands	20
	Thin conglomerate at base	
	Soft, yellow micaceous sands of unknown age; seen for	2
Upper Lias—clay		

Here the Carstone is a feebly cemented mass of coarse sand grains coated with iron oxide, along with pebbles of white quartz, black lydian stone, oolitic ironstone, buff sandstone and phosphatic nodules, and is riddled with thin veins of ironstone. The layer of conglomerate at its base is made up of bored phosphatic nodules of varying sizes in a coarser greensand matrix. The passage into the overlying Red Chalk is gradual and there is no sign of unconformity. For some distance north of Kirby Underdale the coarse and varied Lower Cretaceous deposits are absent and no rocks of this age are met with until the northern edge of the Wolds is reached. There, on the hillside south of Knapton, they reappear as the Speeton Clay facies, the upper beds being exposed at West Heslerton. These clays persist below the Red Chalk eastward to the coast where their full development is seen in the cliff below Speeton. Owing to the unstable nature of the Speeton cliffs, very little of the 296 ft. of clays between the Kimmeridge Clay and Red Chalk has been available for study for a number of years. Our knowledge of these beds is largely due to the work of Lamplugh who thought the section represented an unbroken sequence. Later work by Dr. L. F. Spath on the ammonite fauna has, however, revealed numerous faunal non-sequences; he has shown that the uppermost part of the Kimmeridge Clay, Portland and Purbeck beds and several zones represented at the base of the Neocomian of other countries are all absent and that there are several non-sequences within the Speeton Clay.

STAGES	SPEETON			ft in	LINCOLNSHIRE
ALBIAN			RED CHALK (Cenomanian in part)		RED CHALK
		GAULT	Red and mottled glauconitic clay	8	
			Banded light and dark grey clay	1 9	
			Brown and grey clay with greensand and eroded nodules	4	CARSTONE
			NON-SEQUENCE		
UPPER APTIAN			'EWALOI MARL Light and dark grey clays and marls	5 0	SUTTERBY MARL
			NON-SEQUENCE		
LOWER APTIAN	BRUNSVICENSIS BEDS		Upper 'B' Beds Blue and black clays	23 0+	FULLETBY BEDS
			NON-SEQUENCE		
BARREMIAN			CEMENT BEDS Light blue clays with cement stones	24 0	UPPER TEALBY CLAY
			Lower 'B' Beds. Light and dark clays with layers of nodules	90 0+	TEALBY LIMESTONE
			NON-SEQUENCE		
HAUTERIVIAN	JACULOIDES BEDS	C1	Mottled clays	9 0	LOWER TEALBY CLAY
		C2	Banded clays		
		C3	ECHINOSPATANGUS BED Pale blue clays with brown nodules	6 0	
		C4	Shaly clays with a nodular 'SHRIMP BED' and other bands of nodules	25 0	
		C5	Light and dark clays with hard ferruginous seams	28 0	
		C6	MAIN SPEETONENSIS BED Clays with brown nodules	15 6	
			NON-SEQUENCE		
		C7	Dark clays with stony bands	6 6	CLAXBY IRONSTONE (A condensed deposit) 23 ft.
		C8	Blue and striped clays	6 6	
		C9	Blue and black clays with nodular seams	9 6	
		C10	Pale blue-grey clays	3 0	
		C11	Dark blue clays with a green shelly seam	4 6	
		D1	COMPOUND NODULAR BED Dark clay with large concretions	1 0	
		D2	MAIN POLYPTYCHITES BED Dark gritty clay	4 0	
			NON-SEQUENCE		
VALANGINIAN	SUBQUADRATUS BEDS	D3	Striped pyritous clays	4 0	HUNDLEBY CLAY 18 ft.
		D4	ASTARTE BED. Dark pyritous clays	11 0	
		D5	LINGULA BED Hard black clay with bright pyrites	5 0	
	LATERALIS BEDS	D6	BLUE BED Pale blue-grey clay	4 6	
		D7	Mottled and striped clays	4 0	
		D8	Hard black gritty shale	1 0	
			NON-SEQUENCE		SPILSBY SANDSTONE (INFRA-VALANGINIAN)
		E	COPROLITE BED Basement bed with derived Jurassic ammonites	- 4	BASEMENT BED with derived Jurassic ammonites
			UNCONFORMITY		
	KIMMERIDGE CLAY				

FIG. 20.—*Correlation table of the Speeton Clays with the Lower Cretaceous deposits in Lincolnshire.*

The lithological details of the succession are incorporated in Fig. 20. The Basal Coprolite Bed is capped by a thin band of phosphatic nodules and contains eroded casts of Kimmeridgian ammonites. The '*lateralis*' beds show evidence of slow accumulation which, at times, was interrupted by current action; in these beds fossils are poor but species of the belemnite *Acroteuthis* are common. The *subquadratus* and *jaculoides* bed are mainly banded clays which accumulated slowly in fairly deep water and in them

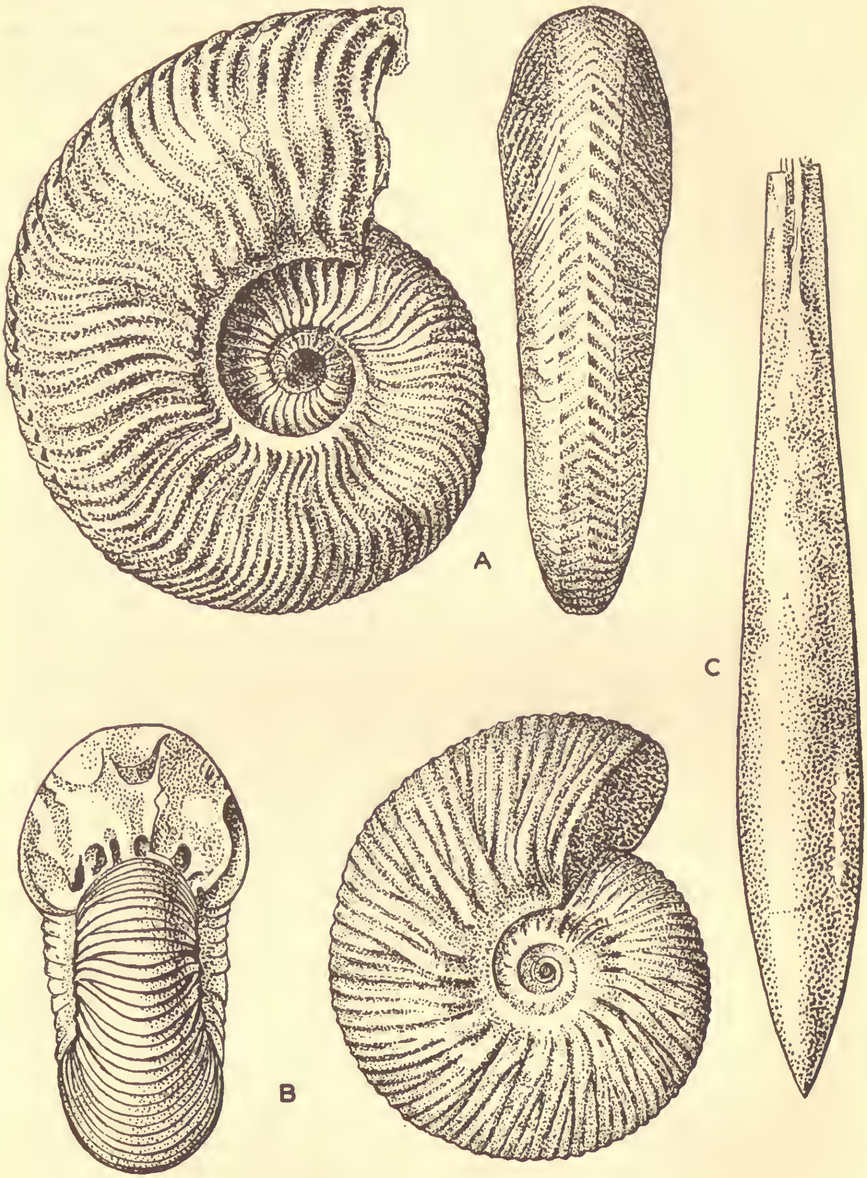

FIG. 21.—*Speeton Clay Fossils.*
(All natural size)

A. *Lyticoceras regale* (Bean).
B. *Dichotomites ramulicosta* (Pavlov).
C. *Hibolites jaculum* (Phillips).

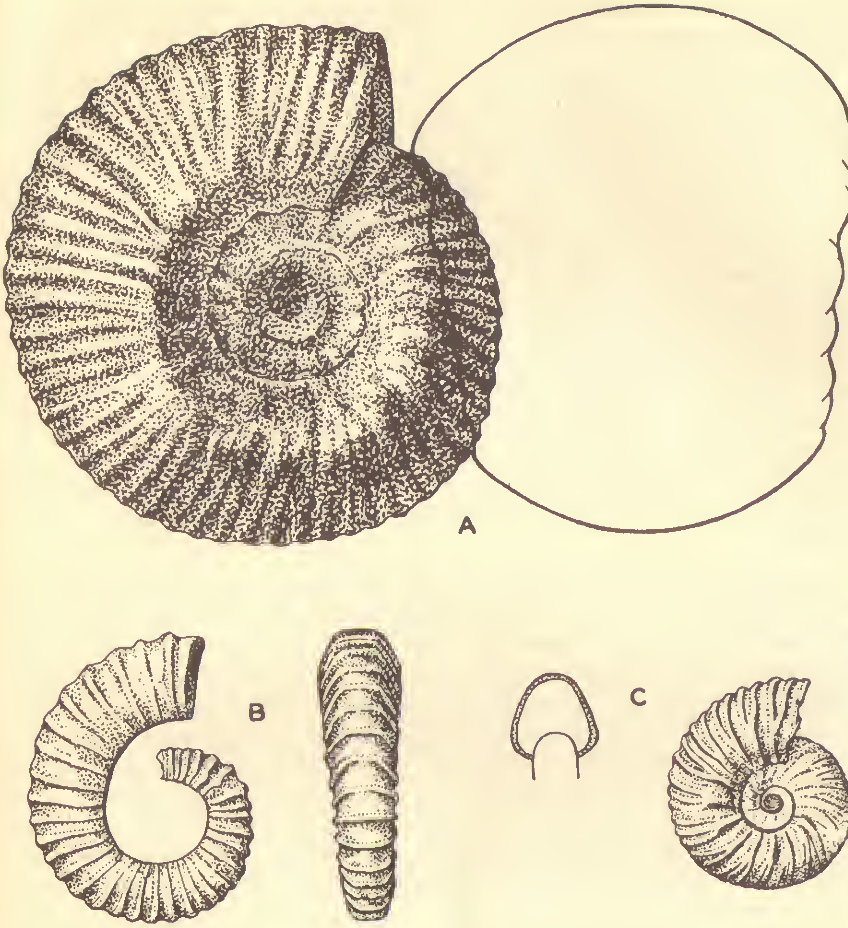

FIG. 22.—*Ammonites from the Speeton Clay.*
(All natural size)

A. *Polyptychites gravesiformis* (Pavlov).
B. *Aegocrioceras capricornu* (Roemer).
C. *Simbirskites concinnus* (Phillips).

ammonites are abundant and enable many of the Continental Neocomian zones to be recognized. The '*brunsvicensis*' beds comprise a considerable thickness of light and dark clays and in the upper part there are numerous layers of cementstone nodules; the belemnite fauna of these beds is quite distinct from that of the *jaculoides* beds below. Marls and clays complete the remainder of the series up to the Red Chalk; the lowest part, the '*ewaldi*' marl is characterized by the presence of *Neohibolites ewaldi* (Strombeck) and *N. fusiformis* (Miller), while *N. listeri* (Mantell) occurs in the higher beds. In beds D4 and D5 it is interesting to note the presence of *Lingula ovalis* J. Sowerby, a small brachiopod of a genus which has persisted since Ordovician times to the present. Bed C4 contains a remarkable line of nodules, most of which enclose the remains of a shrimp, ***Meyeria ornata***

(Phillips); while from bed C3 above comes a profusion of the small sea-urchin, *Toxaster complanatus* Agassiz.

The detailed researches of Dr. L. F. Spath on the ammonites and Professor H. H. Swinnerton on the belemnites have enabled a fairly accurate correlation to be made between the Speeton Series and the Lower Cretaceous deposits of Lincolnshire. The Spilsby Sandstone has been shown to be of Infra-Valanginian age and therefore older than any of the beds of the Speeton Series. The Hundleby Clay which is a facies of the Claxby Ironstone possesses faunal characters in common with the Speeton beds D3–5, while the condensed Claxby Ironstone is to be correlated with bed D2 at Speeton. Ammonites and belemnites common to both serve to correlate the Tealby Limestone and Upper Tealby Clay with the lower part of the *brunsvicensis* beds. The Upper Tealby Clay has yielded species of *Aulccoteuthis* which, in Germany, are associated with *Hoplocrioceras fissicostatum* (Roemer); the same or similar forms of this ammonite also occur in the lower part of the *brunsvicensis* beds at Speeton. The presence of *Oxyteuthis depressus* (Raspail) and *Neohibolites ewaldi* (Strombeck) in the Sutterby Marl link it with the '*ewaldi*' marl, in which these two belemnites are also common.

Though the Lower Cretaceous strata of Lincolnshire are markedly different lithologically from the Speeton clays in East Yorkshire, Professor Swinnerton has suggested that both facies accumulated in a continuous basin covering East Lincolnshire and East Yorkshire up to the time of the formation of the Sutterby Marl. In the interval between the formation of the Sutterby Marl and the Carstone Grit, uplift and extensive erosion took place in the Humber region and a considerable part of the Lower Cretaceous sediments was removed. This uplift and erosion resulted in the progressive decrease in thickness northward of the Lower Cretaceous rocks in Lincolnshire. At the southern end of the Lincolnshire Wolds the effect of these physical changes was limited to a slowing down and possibly a cessation of deposition.

RED CHALK

Separating the White Cbalk from the underlying Carstone in Lincolnshire and south Yorkshire and from the Speeton Clay series on the Yorkshire coast, is a thin but conspicuous bed known as the Red Chalk. This is an impure limestone, varying in colour from pink to brick-red, and contains rounded quartz grains. It is continuous throughout Lincolnshire and is 24 ft. thick at the southern extremity of the Wolds but gradually diminishes in thickness northward, until only 3 to 5 ft. are found north of Audleby. As already noted (p. 58) there is a gradual passage from the Carstone into the Red Chalk. North of Caistor, the Red Chalk successively overlaps all the Lower Cretaceous subdivisions until beyond Audlehy it rests directly on the eroded surface of the Kimmeridge Clay and this condition persists to the Humber. In this district the Carstone grit is missing but the lower part of the Red Chalk is conglomeratic in character, quartz grains and phosphatic nodules being present in fair abundance. In Yorkshire, at thiee localities, Goodmanham, Millington and Kirby Underdale, the Carstone reappears as a few feet of ferrunginous sands resting unconformably on Jurassic strata, but passing up gradually into the Red Chalk which is about

5 ft. thick. The influence of the Market Weighton axis is again brought out by the Red Chalk resting directly on Lower Lias clays and being markedly conglomeratic. Along the norther edge of the Wolds to the sea the Red Chalk rests unconformably on the Speeton Clay Series. Fossils are fairly common and include the brachiopods '*Terebratula*' *capillata* d'Archiac and '*T.*' *biplicata* J. Sowerby, the lamellibranchs *Inoceramus tenuis* Mantell, *I. sulcatus* Parkinson, *Plicatula minuta* Seeley, *Ostrea vesicularis* Lamarck and the small belemnite *Nechibolites listeri* (Mantell).

The Red Chalk represents a much condensed deposit which accumulated slowly and its colour is probably due to red mud washed from a low-lying lateritized contemporary land area. Most of it belongs to the Upper Albian whereas at Speeton only the lower part of it is of that age, and the upper beds, along with the Lower Chalk, are Cenomanian.

Upper Cretaceous

The Chalk

The Chalk marks the end of the continuously changing conditions of sedimentation responsible for the varied strata just described. During the deposition of the Red Chalk a general subsidence began and the sea spread far and wide over the British Isles. Subsidence persisted for a long time and a great thickness of calcareous ooze accumulated, which on consolidation became the familiar chalk.

The Chalk is the dominant formation in the East Riding of Yorkshire wbere it is about 1,400 ft. thick; of this thickness over 1,000 ft. is referred to the Upper Chalk. In Lincolnshire tbe Lower and Middle Chalk amount to about 210 ft. and the greater part of the Upper Chalk has been reduced by pre-Glacial and Glacial erosion to less than 100 ft. which belongs to the *Holaster planus* Zone. The Chalk is wholly marine in origin and much of it is entirely free from terrigenous material. It may owe its purity as a limestone to an arid climate on distant land areas of no great altitude from whicb the small amount of surface drainage that reached the sea carried material in solution. Microscopically, tbe Cbalk is seen to be composed of fine—presumably chemically precipitated—particles, minute spheroidal bodies, foraminifera and small fragments of shells.

In passing northwards from the southern counties into the area, the general aspect of the bauna of the Cbalk changes, becoming more akin to that of the Chalk of north-west Germany. Such ammonites as *Schloenbachia* and *Acanthoceras*, etc., common and familiar in the Chalk of southern England, are rare in Lincolnshire and Yorkshire. Such familiar sea-urchins as *Micraster coranguinum* and *Offaster pilula* are rare, while such forms as *Infulaster excentricus* and *Hagenowia rostrata*, exceptional in the south, are abundant. Ammonites are scarcely known above the Chalk Rock in the southern counties, but in Yorkshire *Scaphites* and uncoiled forms, with such ammonites as *Hauericeras*, are by no means rare in tbe higher beds. These differences bave led to the recognition of a local series of zonal index-fossils, which are compared with the standard series in the following table (the names in the right-band column are here used).

ZONES OF THE CHALK

	S. England	Lincs.	E. Yorkshire
Upper Chalk	*Actinocamax quadratus*		*Inoceramus lingua*
	Offaster pilula		
	Marsupites testudinarius		*M. testudinarius*
	Uintacrinus		*Uintacrinus westfalicus*
	Micraster coranguinum		*Hagenowia rostrata*
	M. cortestudinarium	*M. cortestudinarium*	*M. cortestudinarium*
	Holaster planus	*H. planus*	*H. planus*
Middle Chalk	*Terebratulina lata*	*T. lata*	*T. lata*
	Inoceramus labiatus [=*Rhynchonella cuvieri*]	*I. labiatus*	*I. labiatus*
Lower Chalk	*Holaster subglobosus*	*H. trecensis*	*H. trecensis*
	Schloenbachia varians	*H. subglobosus*	*H. subglobosus*

Differences in lithology permit a threefold subdivision of Upper, Middle and Lower Chalk. Marl bands are of frequent occurrence. One of these, known in Yorkshire as the ' black band ' is 1½ ft. thick and marks tbe top of the Lower Chalk; in Lincolnshire and throughout the rest of England it yields the belemnite *Actinocamax plenus* (Blainville) and is often referred to as the Belemnite or Plenus Marl. Other marly bands of lesser thickness down to mere films are also present; these are frequently curiously contorted and are known as suture bands from their appearance in section. The phenomenon is probably due to sbrinkage and movement caused, in part at any rate, by solution and removal of calcareous matter.

LOWER CHALK

The Lower Chalk in Lincolnshire is mainly comprised of the Grey Cbalk in the lower part, with some pink and light grey chalk forming the upper part. The thickness, 75 to 80 ft., remains constant northward across the Humber to South Cave, beyond which it is reduced to about 60 ft. at Leavening, but towards the coast it thickens again and reaches 125 ft. at Speeton. At the south end of the Lincolnsbire Wolds the Grey Chalk is about 34 ft. thick. It has two well-defined bands at the base; the Sponge Bed, 1½ ft. to 4 ft. of pure hard limestone, is usually yellowisb white but may be slightly pink and is then difficult to distinguish from the Red Chalk below; and the *Inoceramus* Beds, 4 to 6 ft., in two or three beds, parted by marl, of rough gritty cbalk full of the shells of the lamellibranch *Inoceramus*.

Tbe Grey Chalk itself is made up of irregular thin beds of rough grey chalk with partings of marl towards the top. About 3 or 4 ft. of hard rough grey chalk represent the Totternhoe Stone and, like tbat stone, it is composed of ground shell fragments with foraminifera and glauconite grains.

Next comes a bed of grey nodular chalk, with large ammonites, which forms the base of the overlying thick beds of hard chalk.

These are usually white, apart from the lower 6 to 7 ft. which are pink in colour, and somewhat marly except in the Louth district, where it is again pink. The upper limit of the Lower Chalk throughout Lincolnshire is marked by the Belemnite Marls. These average 1½ to 3 ft. in thickness and consist of soft grey laminated marl, often speckled with purple or brown and the lowest layer generally contains numerous pebbles of hard chalk. They owe their name to the restricted occurrence within them of the belemnite

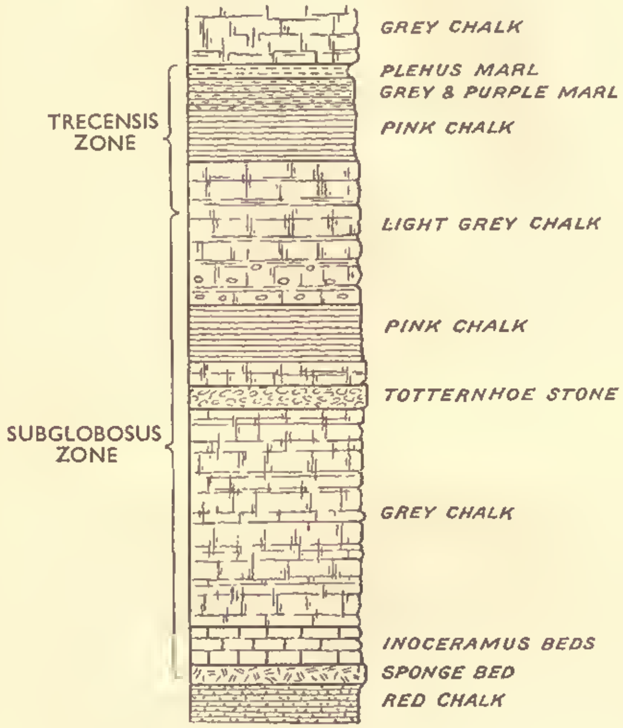

FIG. 23.—*Vertical section of the Lower Chalk of Lincolnshire*

Actinocamax plenus (Blainville). The Lower Chalk of Yorkshire is, on the whole, similar to that of Lincolnshire. A hard white limestone at the base overlies the Red Chalk and is followed in turn by the hard grey shelly *Inoceramus* Bed, and rough grey nodular chalk which weathers into thin platy fragments. These beds total from 25 to 31 ft. along the western escarpment of the Wolds, but at Speeton, where they are more marly and often tinged with pink, expand to about 77 ft. The Totternhoe Stone, represented by 1½ ft. of grey shelly chalk, is succeeded by a few feet of hard chalk and then by a series of beds of soft marly chalk, often coloured pink. At the top of these beds a thin band of marl is referred to the Belemnite Marl, but as yet it has not yielded the characteristic belemnite.

Fossils occur in most of the beds of the Lower Chalk in Lincolnshire and Yorkshire but are not plentiful. In the Grey Chalk there are occasional ammonites of the genus *Schloenbachia*, and the oyster *Ostrea vesicularis* Lamarck is abundant. *Exogyra conica* (J. Sowerby), *Inoceramus crippsi* Mantell, *I. anglicus* Woods, *I. etheridgei* Woods, *Plicatula inflata* J. de C. Sowerby, *Lima globosa* (J. Sowerby), *Pseudolimea spp.*, *Entolium orbiculare* (J. Sowerby) and *Oxytoma seminudum* (Dames) are other characteristic

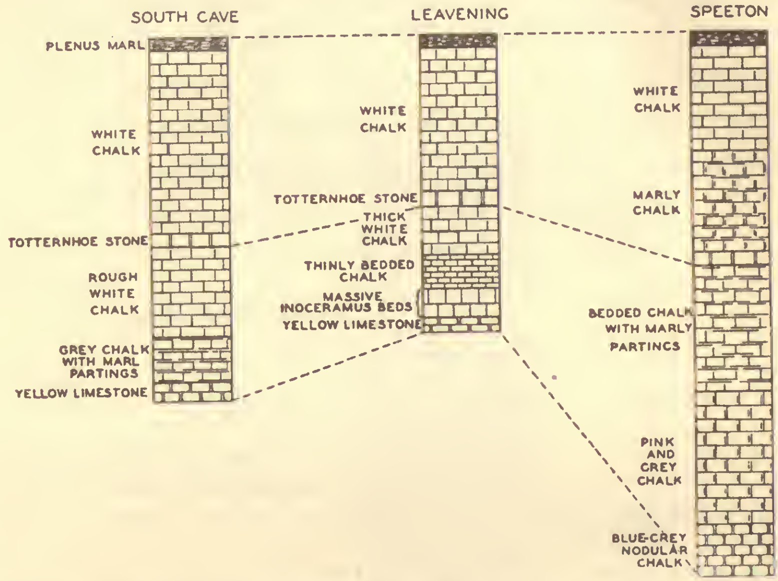

FIG. 24.—*Comparative vertical sections in the Lower Chalk of East Yorkshire.*

lamellibranchs. Terebratulids are common, especially species of *Ornatothyris* at South Ferriby, on the south bank of the Humber. *Terebratulina ornata* Roemer is common in the Lower Pink Band. Among sea-urchins, *Holaster subglobosus* (Leske) occurs in the lower part and is replaced by *H. trecensis* (Leymerie) in the upper beds. *Discoidea cylindrica* (Lamarck) occurs with *Echinocorys sphaericus* Schlüter. Other fossils include the worms *Serpula antiquata* J. de C. Sowerby and *S. umbonata* (Mantell). Isolated valves of the cirripede *Zeugmatolepas mockleri* Withers are common in the Subglobosus Zone of Yorkshire.

MIDDLE CHALK

In East Anglia and the south of England the Melbourn Rock succeeds the Plenus Marls at the top of the Lower Chalk, but in Lincolnshire and Yorkshire there is no such rock, though 10 to 13 ft. of grey shelly chalk with numerous marly partings contain perfect specimens of the lamellibranch *Inoceramus labiatus* (Schlotheim) and the brachioped '*Rhynchonella*' *cuvieri* d'Orbigny, both regarded as index fossils for this subdivision.

In addition, the following have been recorded mainly from Lincolnshire; '*Terebratula*' *biplicata* J. Sowerby and '*T*' *semiglobosa* J. Sowerby (also found in Yorkshire), *Ostrea vesicularis* Lamarck and a *Holaster*.

Overlying the Zone of *Inoceramus labiatus* in Lincolnshire are 120 ft. of thick beds of chalk with nodular flints and at the bottom a distinctive 6-in. band of compact white chalk known as the ' Columnar Bed ', so named because it is traversed by vertical joints and weathers into characteristic rectangular blocks. These beds are referred to the Zone of *Terebratulina lata* Etheridge, a small flat brachiopod with fine divergent ribs. Species of *Inoceramus* are common throughout along with small Terebratulids, *Rhynchonella reedensis* Etheridge, *Conulus subrotundus* (Mantell) and a few rarer forms.

In Yorkshire, the Labiatus Zone comprises the grey shelly chalk beds with overlying white chalk in which layers of flints are seen in some localities and not in others. These white chalk beds vary in thickness; some 26 ft are known at Hessle while 50 ft. of them are present near South Cave, but only 11 ft. are present on the coast. The remainder of the Middle Chalk, amounting to about 210 ft., in Yorkshire comprises thick beds of chalk with nodules of flint and occasional seams of marl. Near the base one or two beds of hard chalky limestone resemble the Chalk Rock of the southern counties. This flint-bearing chalk is included in the Zone of *Terebratulina lata*. The Labiatus Zone in Yorkshire is poorly fossiliferous except for the zonal species of *Inoceramus* and the brachiopod '*Rhynchonella*' *cuvieri* d'Orbigny. The Terebratulina Zone yields the zonal brachiopod abundantly in the form of iron-oxide casts, also *Conulus subrotundus* (Mantell), *Holaster planus* (Mantell) and *Inoceramus lamarcki* Parkinson. At Wharram large ammonites (*Lewesiceras*) occur and numbers of palatal teeth of the ray *Ptychodus* have been found at Hessle. In this zone, fossils are generally rare outside definite bands.

UPPER CHALK

For many years no Upper Chalk was recognized in the Lincolnshire succession until the work of Rowe and various local enthusiasts showed that about 90 ft. should be referred to thc Zone of *Holaster planus* while the Cortestudinarium Zone probably occurs near Ulceby. These beds are found only in north Lincolnshire and are well exposed in pits around Louth; they comprise thick beds of hard homogeneous white chalk with occasional thin marly bands and frequent layers of Oysters and Echinoids. Grey flint is common throughout as characteristic tabular masses reaching a foot in thickness. In Southern England this subdivision contains, at or near the base, the Chalk Rock, a hard cream-coloured limestone with phosphatic nodules and glauconite grains, but in Lincolnshire no representative of this bed is present and in consequence the line of demarcation between tbese beds and the Terebratulina Zone below is difficult to define. The remainder of the Upper Chalk, amounting to many hundreds of feet, has been eroded from the Lincolnshire Wolds.

Across the Humber, in Yorkshire, the Upper Chalk is about 1,050 ft. thick and though it is generally unfossiliferous, each zone has yielded a charactertistic assemblage of fossils.

In the Planus Zone, 125 ft. thick, there is again the homogeneous white chalk with tabular grey flints as at the same level in Lincolnshire. *Holaster planus*, *Infulaster excentricus*, '*Rhynchonella*' and *Inoceramus lamarcki* are common. In tbe coast-section a thick band of *Ostrea vesicularis* is seen.

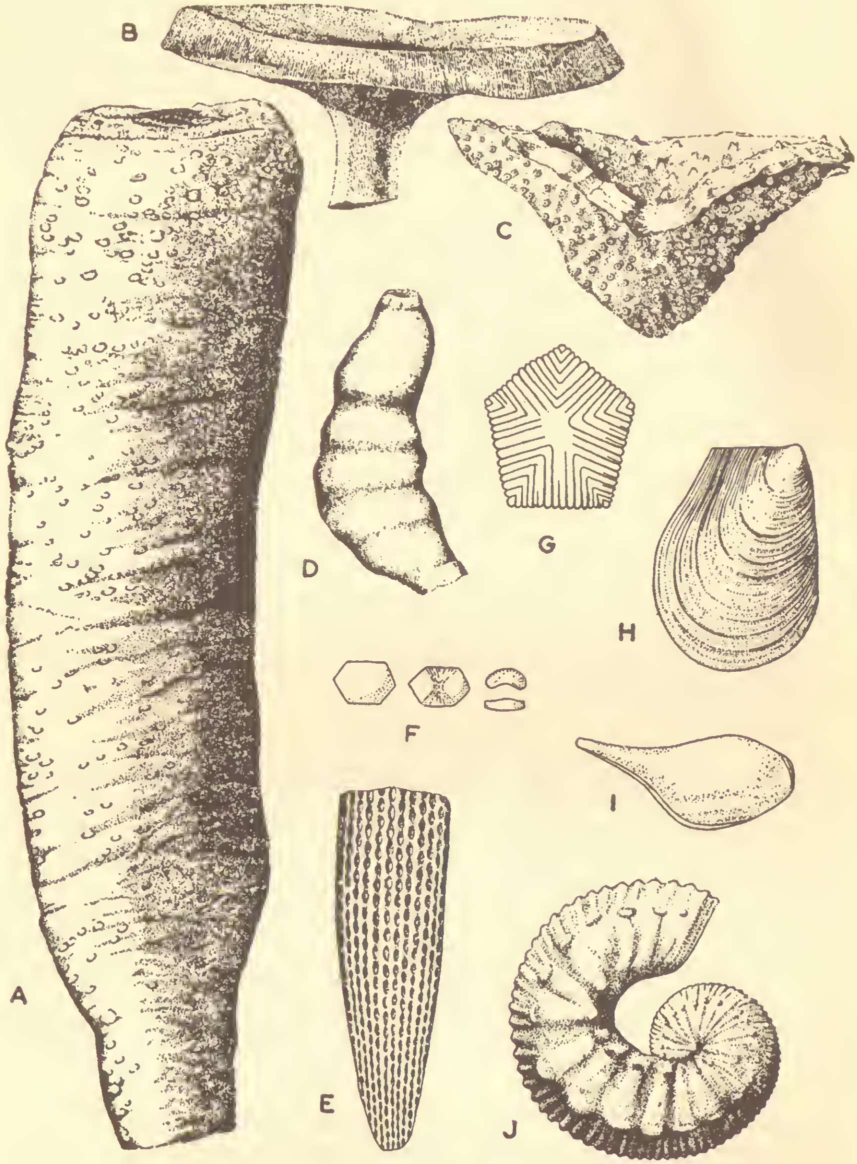

FIG. 25.—*Fossils from the Chalk.*

(G, F and I natural size, others half natural size)

A, *Isoraphinia texta* (Roemer); **B,** *Seliscothon planus* (Phillips); **C,** *Verruculina macrommata* (Roemer); **D,** *Scytalia radiciformis* (Phillips); **E,** *Ventriculites cribrosus* (Phillips) (A-E from the Flamborough Sponge Bed); **F,** *Uintacrinus socialis* Grinnell; **G,** *Marsupites testudinarius* (Schlotheim); **H,** *Inoceramus lingua* Goldfuss; **I,** *Hagenowia rostrata* (Forbes); **J,** *Discoscaphites binodosus* (Roemer).

The succeeding 125 ft. of the Cortestudinarium Zone show no change in lithology. The sea-urchin *Micraster praecursor* Rowe, with the group-features characteristic of the zone, is more abundant than *M. cortestudinarium* (Goldfuss). A small form of *Echinocorys scutatus* and large *Inoceramus lamarcki* also occur, as does the rare *Cardiaster cotteauanus* d'Orbigny.

The Rostrata Zone consists of 261 ft. of massive chalk, flinty in the lower part, nodular and flintless above. Among sea-urchins, *Hagenowia rostrata* (Forbes) is abundant, *Micraster coranguinum* (Leske) comparatively rare. The belemnite *Actinocamax granulatus* (Blainville) is common in this and the succeeding zones and *Inoceramus involutus* J. de C. Sowerby is common inland in the flinty part of the zone. At Middleton-on-the-Wolds a number of sponges belonging to genera better known from the Flamborough Sponge Beds (Lingua Zone) occur, preserved in iron oxide.

The 88 ft. of the Uintacrinus Zone are mostly massive and flintless and contain isolated plates of the sea-lily *Uintacrinus* and a truncated form of *Echinocorys scutatus*. Dane's Dyke ravine, Flamborough Head, is one of the few localities in England where complete cups of *Uintacrinus* have been found, and these can be positively identified with the German species *U. westfalicus* Schlüter. Chalk of this zone is well seen on the coast and in the big Whiting Pits at Beverley, where a band near the top of the zone yields large specimens of the radially-ribbed *Inoceramus pinniformis* Willett.

The Marsupites Zone (121 ft. comprises alternations of blocky and flaggy chalk with marl-bands, devoid of flints and with many nodules of marcasite. Plates of the sea-lily *Marsupites testudinarius* (Schlotheim) are common; the rare sea-urchin *Zeuglopleurus rowei* Gregory occurs, also barrel-shaped stem-joints of the sea-lily *Bourgueticrinus*, *Ostrea vesicularis* and '*Rhynchonella*' *reedensis* Etheridge.

The chalk of the Lingua Zone (327 ft.) is similar to that of the Marsupites Zone, with an increasing number of marl-bands. Only the lower part of the zone is seen on the coast, where the famous Flamborough Sponge Beds yield many perfect specimens of *Seliscothan*, *Verruculina*, *Coeloptychium*, *Siphonia* and many other siliceous sponges. *Inoceramus lingua* Goldfuss and *I. balticus* Boehm are common and *Cardiaster ananchytis* (Leske) occurs in bands. The higher part of the zone is only seen inland, where it contains the cephalopods *Discoscaphites binodosus* (Roemer), *Scaphites inflatus* Defrance and hamites of the genus *Glyptotoxoceras*. Other interesting and characteristic fossils include the small, smooth Pecten *Entolium orbiculare*, which is common in the Lower Chalk and sarcely known above it outside Yorkshire, *Oxytoma tenuicostatum* (Roemer) and the cirripede *Zeugmatolepas cretae* (Steenstrup). In the drift deposits good specimens of *Belemnitella mucronata* (Schlotbeim), a fossil which charaterizes a still bigber zone of the Chalk, are frequently found. Though nowhere exposed, it is possible that the Chalk of this Mucronata Zone is present somewhere beneath the cover of drift in Holderness.

The Chalk has been used for lime-burning and making whitening in many parts of Lincolnshire and Yorkshire; and in some cases the flints have contributed to the construction of buildings. Generally the Chalk forms good agricultural land and many thousands of sheep are reared annually on the Wolds.

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VII. THE CLEVELAND DYKE

THE ONLY IGNEOUS rock in the area is the Cleveland Dyke which crosses north Cleveland in a remarkably straight line amidst Keuper Marls and Jurassic shales and sandstones, into which it is intruded; apart from being covered in places by Glacial deposits, it frequently fails to reach the surface. In the region under review, the dyke is first seen in the valley of the Tees near Eaglescliffe station, north of Yarm, and is exposed at intervals over a distance of 31 miles as far as Fylingdales Moor, near Robin Hood's Bay. The dyke rock is a tholeiite or augite andesite with a devitrified glassy base and, in common with other dykes of similar trend in Northumberland and Durham, is believed to be one of a swarm of basic dykes associated with, and emanating from, the Tertiary ignous complex of the island of Mull off the west coast of Scotland. From the measurement of the helium ratio, Messrs. Dubarry and Holmes estimate the age of the dyke as 26 million years, a result which agrees well with its assignment on general grounds to the Miocene Period.

REFERENCE

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VIII. THE PLEISTOCENE AND RECENT DEPOSITS

IN THIS REGION the ' solid ' formations end with the Cretaceous Period, and the succeeding Tertiary epoch was heralded by a general uplift which gave an E.S.E. tilt to the area. This was also accompanied by differential movement which produced the broad Cleveland anticline. During this time the essential features of the present topography and the final development of the valleys were created by the prolonged denudation of this upland area. All this took place during the greater part of Tertiary time.

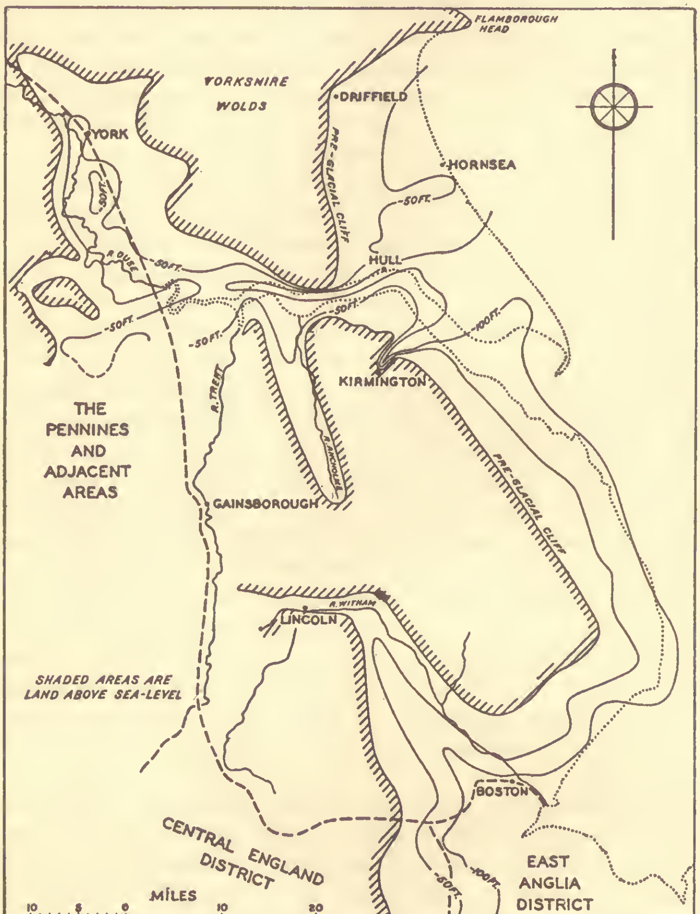

FIG. 26.—*Sketch-map showing pre-Glacial submarine topography.*

Subsequent to the valley cutting there was the accumulation of a miscellaneous assemblage of deposits usually included in the omnibus term of ' Drift deposits '. These fall into two broad categories, those related to present agencies of denudation and accumulation (marine sands, clays and fenland silts, blown sand, peat, warp and alluvium), and the more important category of glacial deposits which characteristically include much material foreign to the district and its river systems. These deposits comprise boulder clay, considered to be the ground moraines of former extensive ice sheets with subordinate frontal morainic material, and water-deposited materials including gravels, sands, silts and laminated clays laid down in extra-glacial areas mainly by melt waters.

Boulder clay fills up many inequalities of the pre-Glacial topography and is indifferent to minor features of relief; in form it occurs as hummocky sheets and moraines. Glacial gravels occur as terraces, beaches and as deposits with forms which are inconsistent with the present river systems but are related to deposition in temporary lakes held up by ice sheets against rising ground. This interpretation is supported by numerous marginal and direct overflow channels from such lakes. Associated, or inter-bedded, with these glacial deposits are numerous fossiliferous gravels, sands and clays which are suggestive of the multiple character of the glaciation and this is confirmed by the distribution of the drifts in their relation to the topography and by the varied character of the boulder distribution.

Glacial Deposits.—Ice sheets caused the removal of weathered rock debris, and laid bare many surfaces which show evidence of grinding, polishing and striation. The eroded material was carried forward by the moving ice and eventually re-deposited at varying distances from its original source. Stones of all sizes transported in this way are termed 'erratics,' and from their character and distribution it is possible to determine the source rocks and the directional trends of the main ice flows.

Boulders of Shap Granite and of Permian Brockram from the Vale of Eden occur in the Vale ol York with Carboniferous and other rocks from the Pennines. Rhomb-porphyry and laurvikite, rocks of Scandinavian origin, are found along the coasts of Yorkshire and Lincolnshire together with rocks from the Chevoits, Lake District and S.W. Scotland. Norwegian erratics are also known in the lower part of the Trent Valley and as far west as Wakefield and Barnsley. In the southern part of the Lincoln Clay Vale chalk and flint erratics of local origin predominate in the Drift.

While individual pebbles and boulders may be scattered over the present land surface they are generally incorporated in a fine clay. This boulder clay varies from place to place but its erratics are characteristically unsorted, scratched and rounded. It may be stiff or sandy, almost stoneless or so stony as to constitute a gravel with a clayey matrix and it may be variable in colour.

Glacial gravels and sands occur in beds and lenses within the boulder clays and as mounds on the surface. Many of the masses of gravel have sharp, straight back slopes from which it is inferred they were deposited directly at the foot of the ice front. Other examples with no ice-contact slope were laid down by streams issuing from the ice or draining the land, or at the lower ends of overflow channels connecting one glacial lake with another, e.g., the gravel delta at the mouth of the Forge Valley overflow channel at West Ayton.

Many of the mounds of gravel ranging across Holderness contain mammalian remains, marine shells and occasionally the freshwater mussel

Corbicula fluminalis (Müller). A deposit of laminated silt with estuarine shells, and peat with marsh plants and some freshwater shells occurs at Kirmington in North Lincolnshire and has been correlated with various patches of shelly shingle found at Kelsey, north of the Humber and elsewhere along the eastern slope of the Yorkshire and Lincolnshire Wolds at and below 100 ft. O.D. These deposits occur between boulder clays and Clement Reid considers that they indicate an integlacial phase.

W. N. Edwards has recently described other patches of locally derived gravels lying close to 100 ft. O.D. between Market Weighton and the Humber. These also may be of the same age as the Kirmington beds and Kelsey gravels. The variations in sea level before and during the Pleistocene Period present a perplexing problem, for throughout the low drift-covered ground in the Ouse basin in Yorkshire there is evidence of a sub-drift topography with river valleys deeply buried below present sea level. These old valleys have been shown by borings to be filled with drift and in many cases to differ widely from the courses of the present river valleys. So far as can be ascertained, these valleys are shallower at their seaward end, than farther inland (Fig. 26).

At Sewerby, near Flamborough Head, an old gravel beach banked against an old chalk cliff (Fig. 27) has been found beneath the oldest boulder clays in the neighbourhood. The underlying chalk floor falls towards the present coast, according to Kendall, at 11 ft. per mile and extends to at least 23 ft. below high water mark. The remains of the straight tusked elephant, *Elephas antiquus* Falconer, the leptorhine rhinoceros, hippopotamus and terrestrial and marine mollusca have been found in this ancient beach deposit. Resting upon it is a mass of chalk rubble or ' head ' and upon this, blown sand and land wash. The cliff backing the beach extends behind and beneath the glacial deposits and is traceable along the edge of the Wolds by Beverley southward to Hessle where it is 80 ft. high, across the Humber and down the eastern flank of the Chalk Wolds in Lincolnshire.

A similar land deposit of chalk rubble similar to that overlying the beach and lying on a chalk floor is recorded by Lamplugh from a boring at a depth of over 100 ft. below surface, and may be the southward continuation at depth of that in the Sewerby section.

In the south of England and on the continent, evidences of early man and his contemporary fauna are frequently found associated in river terraces and in hollows and deep caves in the steep rocky sides of valleys. In our area the now famous Kirkdale Cave—a cave in the Corallian Limestone forming the precipitious east bank of Hodge Beck, near Kirbymoorside, yielded large numbers of Pleistocene mammalian bones in the early part of last century. Here, preserved in the mud floor of the cave, were unearthed the remains of between 200 and 300 hyenas, a canine tooth of a lion, bones of the brown bear, great cave bear, and of the slender-nosed and woolly rhinoceros, the straight-tusked elephant and woolly mammoth; wild cattle were represented by the primeval *Bos primigenius* Bojanus and the bison, also the gigantic Irish elk, red deer and reindeer, together with the remains of wild horse, wolf, fox and many bones of mice and water-voles.

A sequence of Glacial drifts is magnificently displayed in the cliff sections of the Holderness coast and early investigators soon recognized a succession

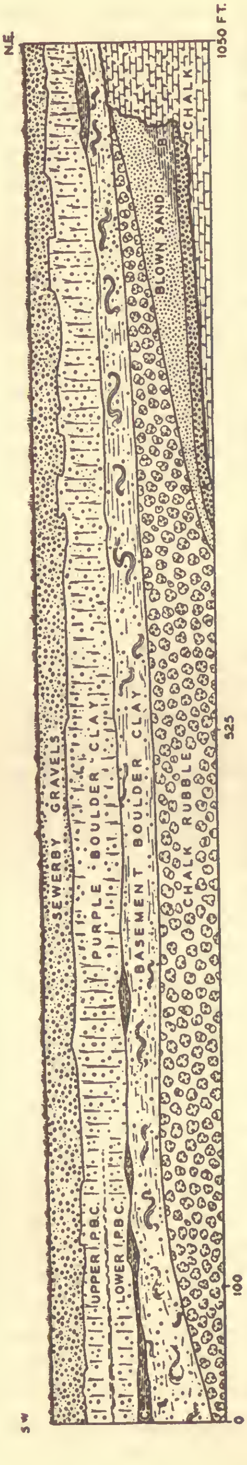

Fig. 27.—*Section at Sewerby near Flamborough Head showing the ancient chalk cliff, 30 to 40 ft. high, and beach deposit below the Drift.*

of four boulder clays with intercalations of gravel, sand and laminated clays, as follows:—

Hessle Boulder Clay—a reddish brown clay
Upper Purple Boulder Clay
Lower Purple Boulder Clay
Basement Boulder Clay—a dark leaden coloured clay.

In East Lincolnshire the succession is much the same as in Yorkshire though sections are few and there the series has a bed of cbalk rubble and flints at its base.

Tbe principal feature of these boulder clays is the varied assortment of erratic boulders and pebbles found in them. Rocks of Scandinavian origin predominate in tbe lower clays while others originating from the Lake District, North of England and Scotland are dominant in the higher clays.

W. S. Bisat, however, disagrees with the above classification and his new interpretation of tbe sequence of boulder clays is summarized as follows:—

9. Upper Purple ..	.. sporadic Scottish erratics
8. Lower Purple	
7. Upper Drab ..	.. chalk and grey flint erratics
6. Middle Drab ..	.. highest beds with Scandinavian erratics
5. Lower Drab ..	.. maximum of granite erratics
4. Sub-Drab ..	.. few arratics
3. Basement Drab	.. incoming of North of England and Scottish erratics
2. Basement Clay ..	.. erratics few and small
1. Sub-Basement Clay	.. Scandinavian erratics dominant

He considers the Hessle Clay of the older classification to be the Middle Drab, or perhaps Sub-Drab Clay.

In the Vale of York, two well marked crescentic terminal moraines of reddish boulder clay and gravel form notable features extending across the width of tbe Ouse plain (Fig. 28). The city of York is situated on one, while on the other is the village of Escrick six miles farther south. Nortb and north-east of York the hummocky features of the southern flanks of the Howardian Hills are largely due to a variable thickness of gravel and boulder clay. In the lower parts of the vales of York and Trent the drifts are patchy and appear to be unrelated to the more northerly drifts; but higher up the Trent Valley and in south-west Lincolnshire are extensive deposits of the Great Chalky Boulder Clay—a grey clay with chalk and flint erratics, the product of the Great Eastern glaciation and, according to Bisat, earlier than the Holderness deposits.

Glacial Lakes and Overflow Channels.—Thick ice on the lower ground frequently blocked many of the valleys and during the declining phases of glaciation melt water and normal drainage water formed temporary glacial lakes. As these lakes were filled up they overflowed round the flanks of spurs and over subsidiary watersheds cutting overflow channels which are independent of the natural drainage valleys and are characterized by their steep sides and flat floors resulting from rapid erosion by large streams of water. Material was carried into these lakes by glacial and natural streams to form deltas, and the overflowing waters from one lake to another also formed deltas of freshly eroded material, the finer sediment being deposited farther out on the floor of the lake. By linking up these deltaic gravels with the levels of tbe marginal and direct overflow cbannels it has been shown that an intricate system of these lakes existed in north-east Yorkshire (Fig. 29). Small lakes were impounded by ice fronts in the valleys draining the northern slopes of Cleveland, and as the more elevated ones were filled up, their waters cut marginal channels leading into lower

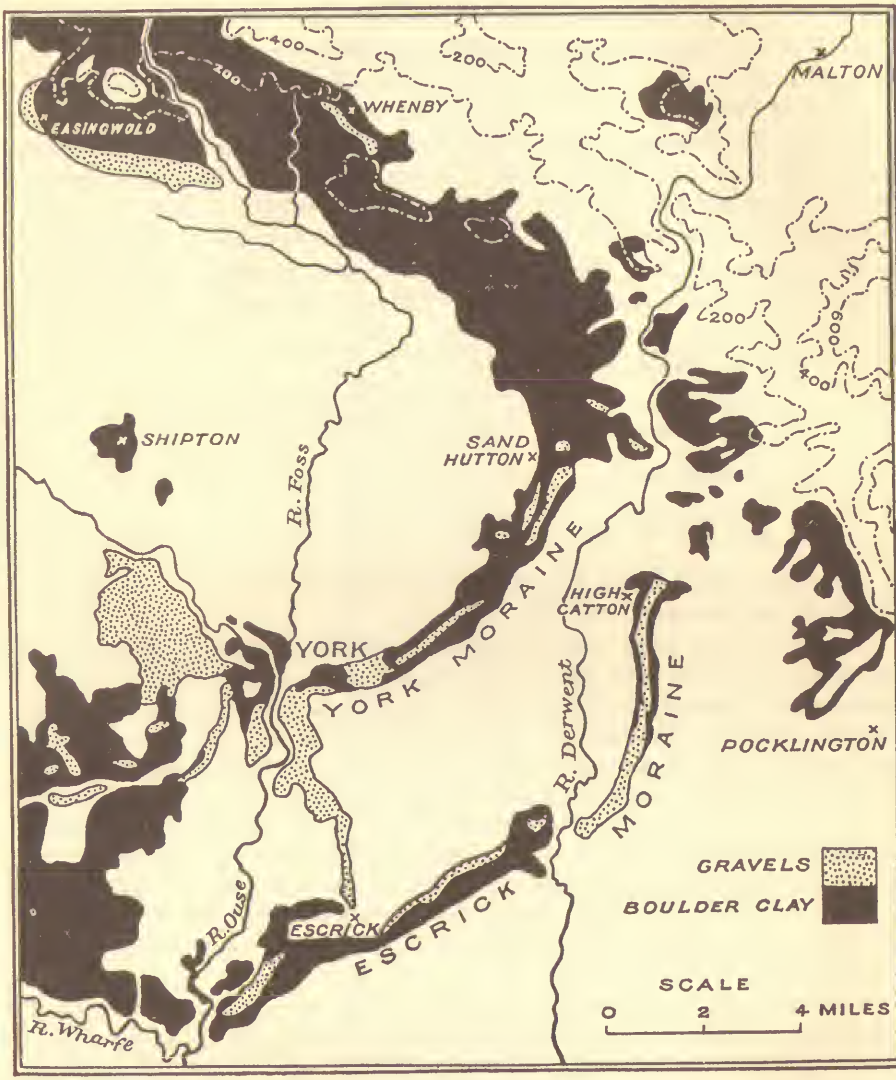

FIG. 28.—*Sketch-map of the York and Escrick moraines.*

lakes and eventually most of this water found its way into Lake Eskdale, which in turn spilled over the lowest part of Cleveland to cut the overflow channel of Newtondale (Plate VIIIA) leading to the vast Lake Pickering.

Another lake was formed in the vicinity of Hackness by ice blocking the seaward end of the Derwent Valley at Scalby and when it was full its overflowing waters passed over a low col in the Corallian escarpment to the south and cut the picturesque gorge of Forge Valley.

A.—GRAVELS AT THE FOOT OF THE ANCIENT CHALK BEACH AT SEWERBY, NEAR BRIDLINGTON

B.—CRUMBLING CLIFFS OF BOULDER CLAY AT ATWICK, YORKSHIRE

[*To face page* 76

A.—NEWTONDALE, A GLACIAL OVERFLOW CHANNEL NEAR PICKERING, YORKSHIRE

B.—SUBMERGED FOREST-BED ON THE FORESHORE AT NORTH FERRIBY, NEAR HULL

FIG. 29.—*Sketch-map showing the Glacial Lakes of Cleveland.* (After Kendall.)

Lake Pickering was formed by ice blocking its western and eastern exits at Coxwold and Filey respectively and when it became filled up its waters topped tbe lowest part of the Howardian Hills, near Kirkham Abbey, cuttiog the fine overflow channel leading to Lake Humber—a still larger lake covering most of the vales of York and Trent. A series of glacial lakes, overflow channels and associated phenomena have also been recognized aloog the lower part of the eastern flank of the Yorkshire Wolds. Most of the melt waters here drained through the Market Weighton gap into Lake Humber.

The bedded drifts south of the Escrick moraine in the Vale of York are of diverse character and show evidence of baving been laid down io water, presumably Lake Humber.

History of the Glaciation.—The bcginning of the Pleistocene Period was marked by a general lowering of temperature, whicb led to the gradual developmeot of glaciers and snowfields on mouotainous regioos culminatiog io the Great lce Age, wben vast sheets of ice spread far and wide over N.W. Europe.

In East Anglia and in tbe valleys of the Thames and Severn a multiple succession of glacial stages has been established with cootrasted Older* and Newer Drifts separated by a period characterized by severe denudation and valley cutting and classed as integlacial. Unfortunately tbe application of this classification to our area is attended by certain difficulties. It is generally accepted that the York moraines mark the southward limit of tbe Newer Drift in the Vale of York, with the ice front of that age swinging back northward round Cleveland and impinging on the coast of Yorkshire, Lincolnshire and Norfolk. South of this ice front only remnants of the Older Drift have been left in Yorkshire after prolonged denudation, and a tbick mass of Cbalky Boulder Clay remains in south Lincoloshire.

Within limits a great problem, as yet unsolved, is involved in the interpretatioo of the coastal drift sections of Yorkshire and Lincolnshire. Some authors consider tbat the Holderness sections show a complete sequeoce of Pleistocene drifts and that tbe Sewerby beach is a pre-Glacial deposit. On the old grouping of P. F. Kendall the classic sections of the Holderoess coast represent several glaciations, but the evidence is incomplete. Otber observers consider that the beach and related deposits at Sewerby represent an interglacial phase and that the bulk of the Holderness deposits are of Newer Drift age, tbe Older Drift having been largely removed.

The Kirmington Beds are later than tbe Sewerby beach deposits; they lie between two boulder clays and are of marine origin, but whether or not these conditions represent a truly interglacial phase with a more genial climate or merely a limited retreat of the ice front giving access to marine waters is uncertain.

If the Holdcrness deposits are of Newer Drift age, then, such Older Drift as remains can only be represented in East Yorkshire by certain patches of weathered material on high ground, imperfectly known and as yet only partially described. In Lincolnshire, however, the Great Cbalky Boulder Clay lying mainly west of the Wolds is generally coosidered to be Older Drift.

* The term 'Older Drift' is here used in the generally accepted sense of drifts of the Great Eastern and earlier stages of glaciation.

Scandinavia was one of the main centres of ice accumulation and a sheet of ice advanced across the North Sea, impinged upon the north-east coast and invaded the low ground of Holderness, Lincoln Marsh and areas farther south, bringing with it erratics of Scandinavian origin and sediment with marine shells swept from the sea bed, eventually leaving it as contorted masses within the boulder clay. Ice from the Cheviots also came south through Northumberland and Durham, while other ice coming from the

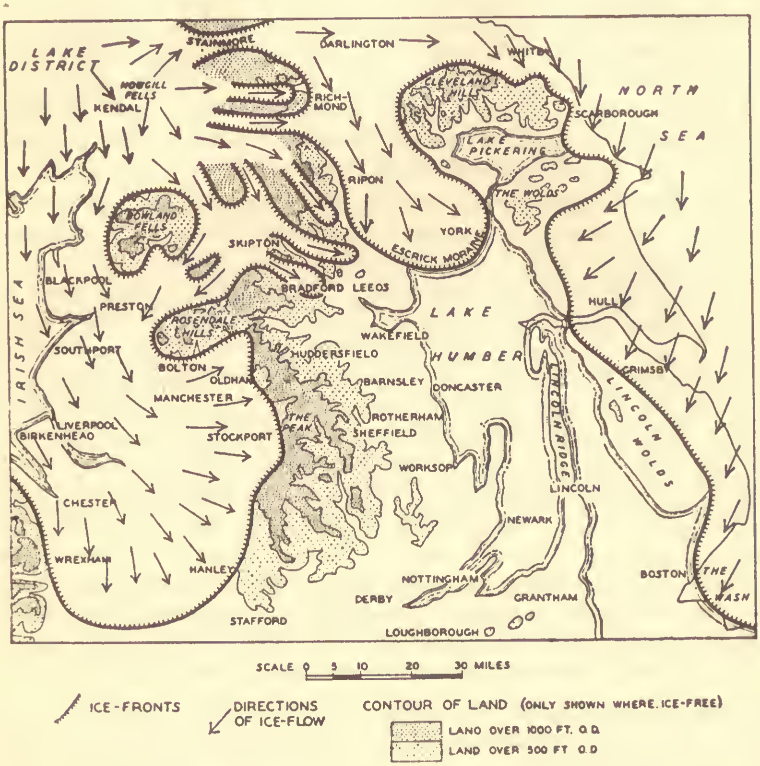

FIG. 30.—*Sketch-map illustrating the later stages in the Glaciation of the North of England when, during the retreat stage, the moraines in the vicinity of York were being formed.* (After Raistrick.)

Irish Sea and Lake District, reinforced perhaps by local Pennine ice, pushed its way over Stainmoor into our area.

At an early stage a northern ice stream advancing down the Vale of York joined with invading ice from the North Sea to produce the Chalky Boulder Clay in Lincolnshire, East Anglia and the Midlands. Some of this ice forced its way over the southern part of the Lincolnshire Wolds and its travel over the different rock formations is reflected in the clay which varies in composition from place to place. The scattered drifts of the Trent Valley may also be products of this ice, for at some stage a lobe of ice carrying Scandinavian erratics must have entered this area, perhaps through the Humber gap.

Prolonged interglacial denudation with drastic dissection and removal of the Older Drifts followed the retreat of this Older Drift ice, which in its subsequent readvances never reached its previous limits. The approximate limits of the ice in the later stages in the glaciation of our, and neighbouring, regions are shown in Fig. 30.

Most of the Newer Drift ice from north-west, north and north-east sources passed to the north of the Cleveland Hills and moved down the coast, but a large ice stream extended down the Vale of York, bringing with it the characteristic Permian Brockrams from the Vale of Eden, blocks of granite from Criffel and Shap, rocks from the Cheviots and local material from the Pennines. The crescentic moraines at York and Escrick mark the limit of this readvance. The Cleveland Hills, Howardian Hills, and the Wolds of Yorkshire and Lincolnshire, though possibly having a cover of snow or nevé, appear to have been free from ice at this time.

The ice streams moving down the coast blocked all the valley exits with boulder clay and laid down the successive sheets of drift in Holderness and East Lincolnshire. The preponderance of Scandinavian erratics in the Basement Clay points to the dominance of North Sea ice in the early stages, but as the ice dispersion from north of England and Scottish centres increased in magnitude so we find in the higher boulder clays a greater proportion of erratics from these sources to the exclusion of those of Scandinavian origin. During the final stage, the vales of York and Trent were occupied by an ice-dammed lake of variable extent; initially it was restricted to the upper part of the Trent Valley by ice which had advanced into the Humber gap; during this early stage scattered patches of laminated clays and gravels were deposited and the lake drained by way of the Honnington gap at Ancaster. As the ice retreated, the less elevated Lincoln gap became operative and eventually when the Humber gap became free of ice it became the final outlet of the lake. During the same phase the marginal drainage along the edges of the waning ice-fronts in north-east Yorkshire gave rise to the intricate system of impounded glacial lakes already referred to above.

Post-Glacial and Recent.—It was on the low ground that the ice sheets abandoned most of their transported material, with the result that in many parts a new surface was built up, with new outlines and modified or new drainage systems. The finishing touches to these new features have been wrought by post-Glacial agencies which are still in operation. The greater part of the Holderness Plain, Lincoln Marsh and the Fens, is clear gain at the expense of the sea, which, in its present-day encroachment is only reclaiming its own. In Fig. 26 an attempt has been made to show the extent to which marine inundation would advance if the drifts were removed from these areas.

The drainage systems in these low-lying areas are entirely post-Glacial, and as the general surface is uniformly low the drainage is sluggish and the original features of the drifts remain unimpaired. In Pleistocene times there were changes in the relative levels of land and sea, and during phases when the land was high relative to sea level, the rivers became more deeply incised.

Submerged Forests.—At some time subsequent to the close of the Glacial Period the land must have been 50 to 100 ft. higher than at the present day and forests abounded. Relics of these forests, in the form of tree-stools still standing in their black peaty earth, occur in the Humber estuary. Sucb trees as the Scotcb fir, oak, hazel, alder and willow can be identified along with much marsh vegetation (Plate VIII B).

Clays, Silts and Peat.—A period of submergence succeeded that of tbe forest growth and with the resulting marine inundation of the low-lying tracts deposits of marine and estuarine silts and clays were laid down. These deposits are extensive in the Fenlands of south-east Lincolnsbire (up to 60 ft.) and over large tracts of the country bordering tbe estuary of the Humber. The alternating conditions under which these deposits accumulated in the Fenlands may be summarized as follows:—

(1) deposition of marine muds and gravels by the sea;

(2) deposition of land silt by rivers on reaching the stagnant marsh-lands lying behind the seaward marine deposits;

(3) the growth of marsh and other plants in such profusion as to form peat beds up to 15 ft. thick.

Inland, some of these deposits were probably in part contemporaneous with the disappearance of the last traces of the ice sheets of adjacent areas. In Holderness lakes and meres occupied the hollows in the irregular surface drift, and ultimately degenerated to peat bogs till eventually most of tbem were drained by man. These peet beds occasionally yield mammalian remains and tree stumps. Peat growth also extended to higher ground where moorland peats indicate a former extensive forest growth in areas now devoid of trees. In the low lands or 'carr-lands' and on some of the broad, flat moors peat is still accumulating, but generally it is being denuded from the hills.

Blown Sand.—In post-Glacial times large quantities of sand have been blown eastwards across the lower part of the Trent Valley and now mask the Jurassic rocks over large areas between Kirton Lindsey, north of Lincoln and the Humber.

Coastal Changes.—On the northern side of the Humber estuary. Holderness is growing in area by deposition of silt and 'warp', partly fine alluvial material caught in its passage out to sea and carried back by the rising tide to be deposited on each flank of the estuary. The reinforcement of these areas is, however, largely by marine wastage of the Holderness coast whicb the tidal currents partly sweep into the Humber estuary. The post-Glacial deposits occurring in the Lincoln Marsh area include a bed of peat at tbe base succeeded by stiff clays capped by a thin peat and followed by a variable thickness of soft purplish clays.

Where Pleistocene deposits form the coast-line they are being actively eroded by subaerial and marine denudation. The destruction of the Holderness coast south of Flamborough is rapid, from 4½ to 7 ft. per year, and within historic times many small towns and villages have been swept away. This material is being carried south by long-shore currents and is contributing to the formation of the Spurn Head peninsula; much of it is also bcing deposited on parts of the Lincolnshire coast north of Mablethorpe and south of Skegness. Between these two places the coast is also being denuded and the material carried southward.

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IX. THE GEOLOGICAL STRUCTURE OF THE REGION

THE GENERAL UPLIFT of the Pennines which began in late Carboniferous times, was renewed after the close of the Cretaceous Period and resulted in

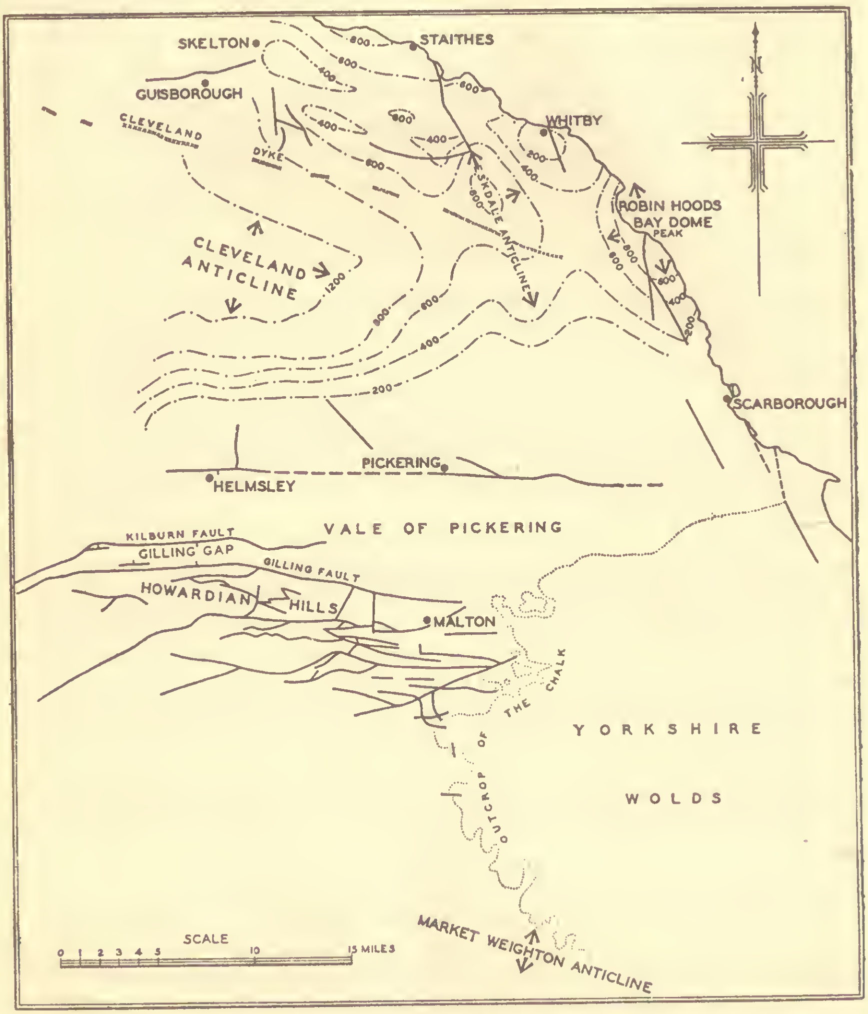

FIG. 31.—*Sketch-map of the structural contours of the base of the Grey Limestone Series in Cleveland, and the Fault-systems in North-East Yorkshire.*

the whole succession of rocks in this area being elevated as an eastward dipping platform. Two major structures are present in this platform, the Cleveland Uplift and the Market Weighton anticline; the former is obvious at the surface, being formed by differential movements in Tertiary times.

The latter is largely hidden but its effects on sedimentation were important throughout Jurassic and Lower Cretaceous times.

The Cleveland Uplift.—This outstanding structural feature is seen in the dissected area of high ground extending from the north Yorkshire coast westward to tbe Vale of Mowhray and known as the Cleveland Hills. It is made up of Liassic and Middle Jurassic rocks which have been elevated in an east-west direction into what was formerly considered to be a simple anticlinal structure pitching out to sea in Robin Hood's Bay. Recent investigations in the area, in which the structural contours for the hases of the Dogger and Grey Limestone Series respectively have been worked out (Fig. 31) have shown that the uplift comprises an elongated Cleveland dome with a trend slightly south of east and north of west with, lying to the east of it, two suhsidiary domes centred on Sleights Moor, south-west of Whitby, and Robin Hood's Bay. These anticlinal structures are separated by complementary troughs and a pronounced basin-like structure is centred on Whitby. In north Cleveland other domes and troughs of lesser magnitude have also heen recognized. Dr. H. C. Versey considers all these structures are of Tertiary age.

Faulting.—The Cleveland area is bordered to the south and east by zones of faulting. That on the south is dominated by the broad trough-faulted structure of the Vale of Pickering and on the east by a series of north-north-west to south-south-east faults in the coastal area. At the western end of the Vale of Pickering is the narrower faulted trough, known as the Gilling Gap, formed by the Kilburn and Gilling faults with throws of 700 to 1,000 ft. and 500 ft. respectively. The Helmsley-Pickering Fault to the north has a throw of nearly 500 ft.

In the zone of faulting on the eastern seahoard the faults trend north-north-west to south-south-east. One of these faults passing through Peak at the south end of Rohin Hood's Bay has had a unique history. It has a throw of some 400 ft. and brings down the Lower Estuarine Series against the Sandy Series of the Middle Lias. Beds of the Jurense Zone are present on its east side but ahsent to tbe west, a discrepancy of 200 ft. due to the initiation of an unstable north-north-west to south-south-east monoclinal fold in Yeovilian times. The structure eventually fractured and such Yeovilian beds as may have been deposited on the upthrow side were scoured away and the material incorporated in the Yellow Beds accumulating to the east of the moving fault. The thinning out of the Dogger as it approaches the fault on its upthrow side indicates continued movement into Lower Estuarine times, after which it ceased and normal sedimentation was resumed in tbe area. In post-Upper Jurassic times it again moved a further 200 ft.

The Howardian Hills to the south of the Gilling Gap are intensely dislocated by an intricate system of post-Jurassic and pre-Cretaceous faults trending west-north-west to east-south-east and north-east to south-west. Although the Chalk farther east has not been affected by this faulting there are lines of crumpling within it which are aligned witb some of these faults. Dr. H. C. Versey suggests tbat some of this faulting may have taken place in post-Chalk times when the incompletely indurated Chalk would crumple ratber than fracture.

The Market Weighton Axis.—Throughout Jurassic and Cretaceous times tbere occurred in various parts of Britain areas of differential movement

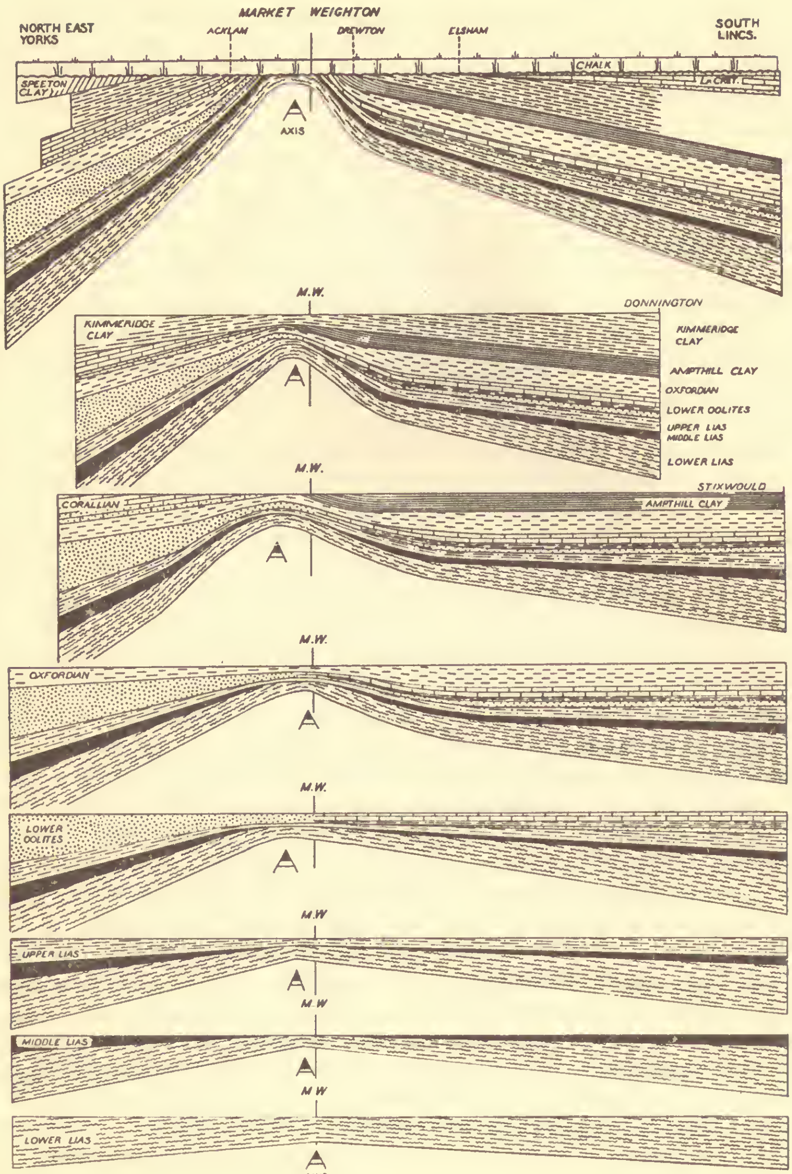

FIG. 32.—*Diagram showing the effect of the Market Weighton axis on sedimentation throughout Jurassic and Lower Cretaceous times.*
The position of the axis is shown by the triangular symbol.

which greatly influenced the character and amount of the sedimentation. One of these critical zones persisted during Jurassic and Lower Cretaceous times in the vicinity of Market Weighton in East Yorkshire. Most of the formations laid down in these times in Yorkshire and Lincolnshire exhibit marked abnormalities in character and thickness as they approach this west-north-west to east-south-east axis.

The Lower Lias in attenuated form is present over the axis; its fauna indicated shallow water conditions while the thinning may be due to the winnowing away of sediment by currents. The Middle Lias is absent, and a reduced thickness of Upper Lias was laid down over the axis. The Middle Jurassic strata, besides showing a marked reduction in thickness on approaching the axis, are also substantially different lithologically in the areas to the north and south of it, and Dr. M. Black considers the axis was a broad, unsubmerged ridge during their formation. Similar attenuations occur in the formations of the Upper Jurassic towards the axis, and the thick Corallian gritstones and oolites of Yorkshire are represented by clays to the south of the axis. Similarly the varied series of Lower Cretaceous beds in Lincolnshire thin out entirely before reaching the Humber and north of the axis they occur in a different facies as the Speeton clays along the northern edge of the Yorkshire Wolds. These attenuations are represented in the sections in Fig. 32.

The movement of this axis ceased at the end of Lower Cretaceous times when further marine denudation took place prior to the deposition of the Chalk which rests directly on the Lower Lias. From his classic study of this structure, P. F. Kendall interpreted the facts to imply a broad ridge almost at sea level which maintained recurring oscillations of small amplitude, while over north-east Yorkshire and south Lincolnshire depression and sedimentation were continuous. Kendall's interpretation accords better with the evidence than the view expressed by Dr. H. C. Versey and Mr. E. M. Beilby that uplift took place along a number of subsidiary anticlines; further, geophysical survey methods fail to reveal any such subsidiary structures.

Structures in Lincolnshire.—Structurally, Lincolnshire is devoid of large scale folding and faulting; however, faulting on a small scale has affected the Middle Jurassic rocks to the north-east and south-east of Lincoln and a trough-faulted structure trends north-west to south-east across the Risby Warren area, near Scunthorpe. A. J. Jukes-Browne inferred a north-west to south-east anticline through Louth and Willoughby to account for the fact that along this line the Glacial drifts lie directly on Lower Cretaceous rocks and not on Chalk as would be expected. Moreover, around Willoughby, the Chalk shows anomalous dips to the west and south-west, though the regional dip of the Wolds is eastward. More recently, Dr. H. C. Versey has deduced an anticlinal uplift passing through Caistor in a direction slightly west of north-west, and he believes its westerly continuation is indicated by the deflections in the outcrops of the Lias and Lower Oolites at Santon and Flixborough, near Scunthorpe. Recent work in this latter area has shown this structure to be a faulted monocline.

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X. ECONOMIC PRODUCTS

Iron.—The region includes two of the most important iron-producing fields in Britain. Many of the rocks of the Lower and Middle Jurassic and

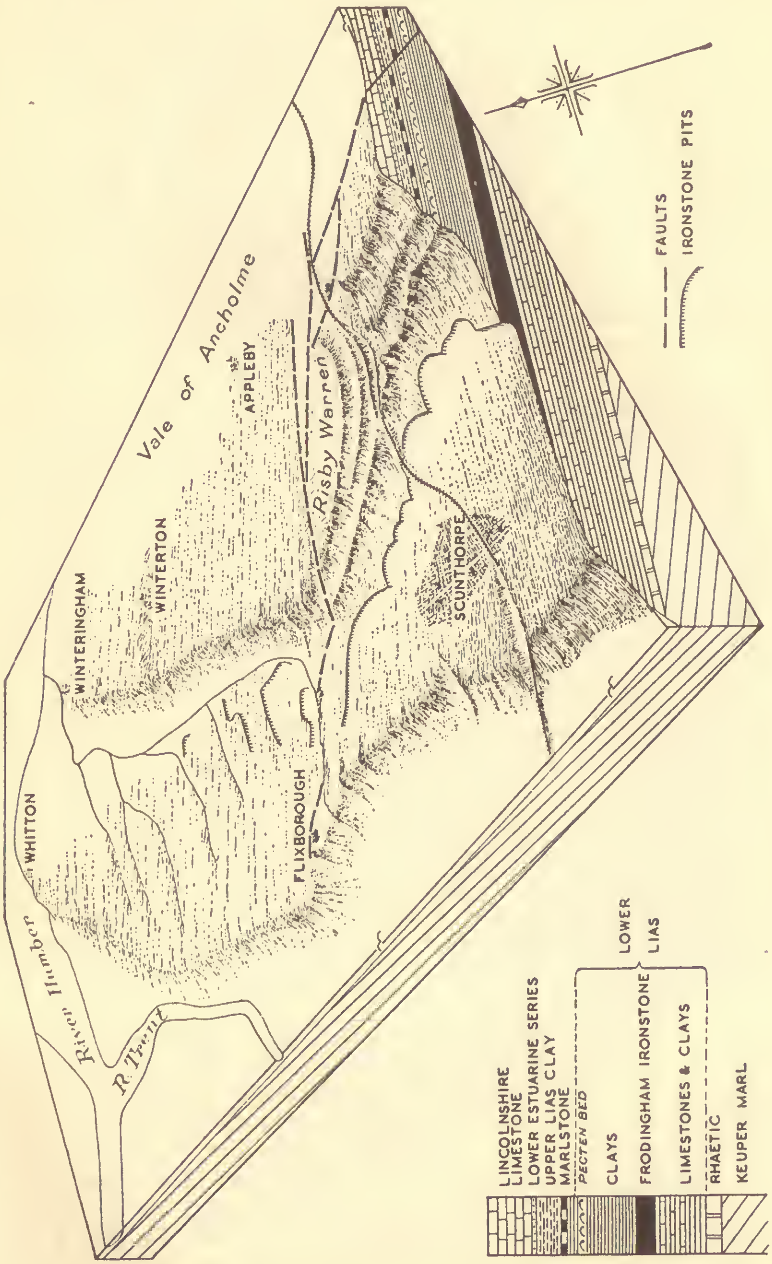

FIG. 33.—*Block diagram of the Frodingham Ironstone field.*

Lower Cretaceous are highly ferruginous and in the past attempts have been made to exploit them. The Frodingham Ironstone in north-west Lincolnshire of Lower Lias age is worked by open cast mining methods over a distance of 7 miles along its outcrop (*see* Fig. 33), and the town of Scunthorpe owes its rise since about 1860 to this industry. The average thickness of this shelly limonite oolite is about 26 ft., most of which is worked. It is a low-grade self-fluxing ore with an average iron content of from 17 to 35 per cent. The Middle Lias carries the great ironstone field of Cleveland and the smaller field in mid-Lincolnshire. In Cleveland there are four seams of chamosite mudstone which, when traced southward, all attenuate and are split by bands of shale. The Main Seam extends from west to east across the field and ranges in thickness from about 11 ft. in the north to under 6 ft. in the south of the worked area; it yields practically the whole of the output of iron ore raised in Cleveland amounting to 2 million tons in 1939. The iron content of the Main Seam reaches up to 30 per cent but the lime content is so low (5 per cent) that quantities of limestone have to be used for fluxing. The ore of the three minor seams is of inferior quality but has been worked in various localities. The variations in the thicknesses of the four seams and their relations to each other are shown in the vertical sections in Fig. 6, p. 23.

The upper 9 to 16 ft. of the Marlstone has been worked for iron ore in South Lincolnshire. The best Marlstone ore is a green, densely oolitic limestone in its unweathered state, yielding from 23 to about 28 per cent of iron. This ferruginous development of the Marlstone fails at Leadenham, 14 miles south of Lincoln.

The Upper Lias shales often include bands of ironstone nodules, but no workable iron-ore has been found.

In South Lincolnshire the rich Northampton Ironstone has been worked in places as far north as Lincoln, beyond which it deteriorates to ferruginous sands with ironstone nodules. It is an oolitic green carbonate yielding from 31 to 38 per cent of iron.

The Dogger in north Yorkshire is ferruginous and locally is sufficiently rich to be worked. A considerable quantity of ore was obtained from this horizon in Rosedale and around Staithes, on the coast.

The Eller Beck Bed often includes persistent bands of oolitic ironstone up to 6 ft. thick and was formerly worked in Glaisdale. The Grey Limestone Series also contains a little impure ironstone in thin bands 6 to 12 ins. thick. The Cornbrash is ferruginous in Ryedale and Newtondale where unsuccessful attempts to work it have been made, and iron also appears to have been obtained from the ferruginous upper part of the Kellaways Rock in ancient times.

At the base of the clay immediately overlying the Spilsby Sandstone there is an oolitic ironstone at Hundleby, near Spilsby, but it is economically unimportant. The Claxby Ironstone, slightly higher in the sequence, crops out along the western escarpment of the Lincolnshire Wolds between Audleby and Donington-on-Bain, where it is mined between Nettleton and Normanby-le-Wold. It is an oolitic clay ironstone with a maximum thickness of about 14 ft. though on the average only about 7 ft. is workable ore, yielding up to 37 per cent of iron. Limonite ooliths and thin seams of oolitic ironstone occur in the Fulletby Beds above the Tealby Limestone and the ferruginous Carstone at the top of the sequence contains about 14 per cent of iron with insoluble constituents ranging from 55 per cent to 68 per cent.

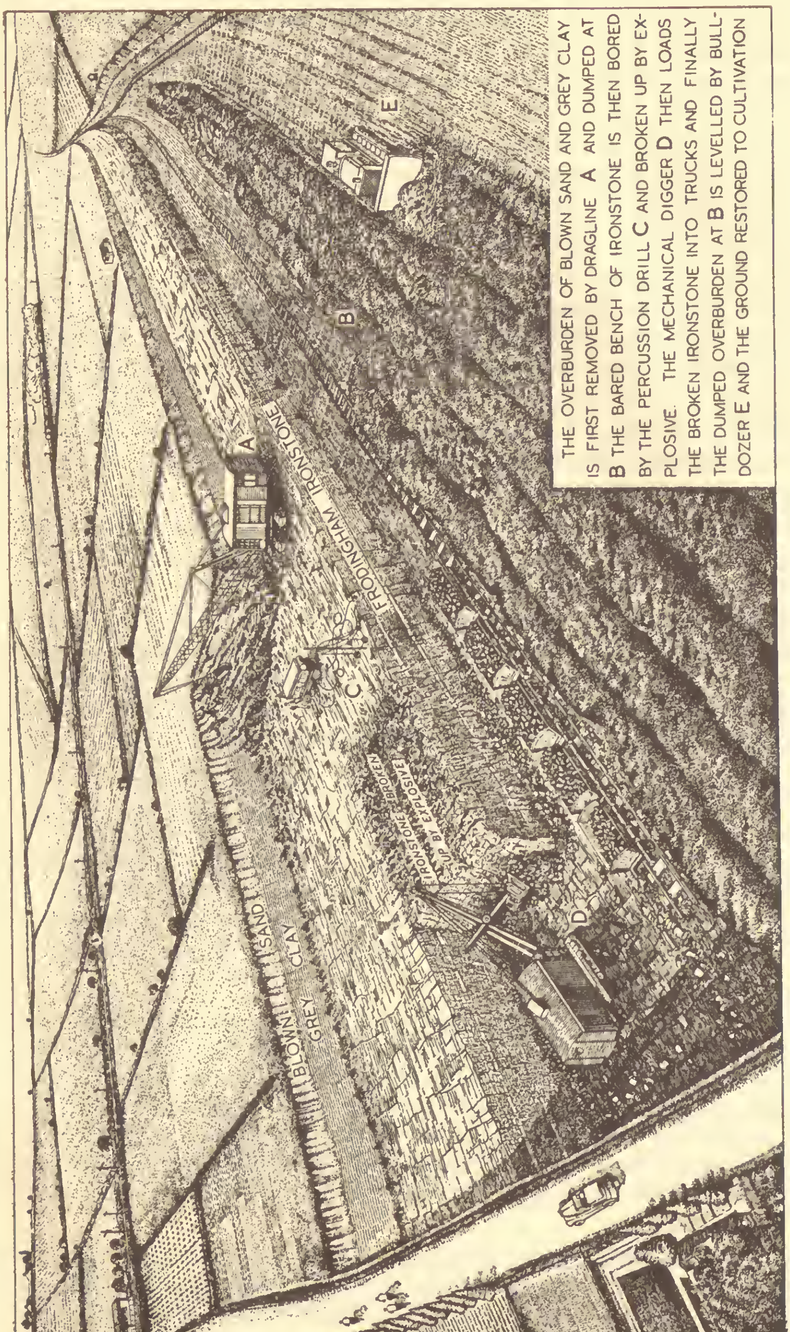

FIG. 34.—*Diagram of a working pit in the Frodingham Ironstone.*

Coal.—Thin impersistent seams of coal occur in the Middle Estuarine Beds in Cleveland, and in the past, one seam usually about 15 in. thick and about 50 ft. below the Grey Limestone, has been worked around Danby in Eskdale. The coal is of poor quality and is only used in lime-burning. A 10-in. seam was also formerly worked to a small extent in the vicinity of Coxwold.

Jet.—Jet has been obtained from the Upper Lias shales of Yorkshire since early times and was described by Caedmon in the seventh century. In the last century a considerable trade in carved objects of jet was carried on in Whitby, but its decline has been rapid since 1873 and it is now almost extinct.

Alum.—The manufacture of alum from the Upper Lias shales, once one of the principal industries of the Whitby district, reached its zenith about 1769 when the annual production was about 6,000 tons, but it declined rapidly and few workings persisted into the early years of last century.

Gypsum.—Thin bands of gypsum occurring in the upper part of the Keuper Marl have been worked at Newark and other localities in the Trent Valley and also in the Vale of York.

Salt.—Rock salt occurs at depth in beds of varying thicknesses at intervals in the Upper Permian rocks in the Middlesbrough district; it is not mined but is pumped out as brine from which the salt is recovered.

Phosphatic Nodules.—The basal nodule bed of the Spilsby Sandstone in Lincolnshire is largely made up of derived phosphatic nodules containing 46.6 per cent of calcium phosphate. The Carstone in Lincolnshire and Yorkshire also contains small derived phosphatic nodules, and similar nodules occurring in the Speeton Clay Series were worked at one time.

Cement.—The Lower Lias limestones in south-west Lincolnshire have been burnt for hydraulic cement, and nodules in the Upper Lias and in the Speeton Clays have also been tried for the same purpose. The Kirton Cementstones, near Kirton in Lincolnshire, and the Kimmeridge Clay, mixed with Chalk, on both sides of the Humber are extensively worked in preparing this commodity. The Upper Calcareous Grit cementstones at north Grimston in the Howardian Hills were a profitable local source of cement down to recent times.

Limestone.—Various Jurassic limestones and certain beds in the Chalk are locally burnt for lime. In Yorkshire, the Dogger has been burnt around Stokesley and at Sutton-under-Whitestonecliff; the Hydraulic Limestone has been similarly used in the neighbourhood of Terrington in the Howardian Hills, and in parts of Cleveland some of the more calcareous bands of the Grey Limestone Series have also been tried. The Millepore Oolite is locally important for this purpose at Whitwell, near Malton, and farther south at Sancton and Brough.

The Hambleton Oolite has also been used to a considerable extent near Kepwick, but the Osmington Oolite has for a long time been the major source of lime in the areas bordering the Vale of Pickering and it is worked extensively in many places. In Lincolnshire the Lincolnshire Limestone has been burnt for lime and the Chalk has been employed in the manufacture of whiting.

Building Stone.—Many of the sandstones and limestones in this area are valuable as building stones. In Lincolnshire, the Marlstone and Ancaster Freestone are well known for this purpose, the latter having been used in the construction of many public buildings in London, Cambridge and elsewhere. At Lincoln the 'Silver Beds' at the base of the Lincolnshire Limestone have been employed in the Cathedral. In the Howardian Hills the Dogger around Terrington was used in the twelfth century in the construction of Sheriff Hutton Castle. Whitby Abbey, Covent Garden, and the foundations of the old Waterloo Bridge and London Bridge and many other public buildings are constructed of Lower Estuarine Sandstone from the Aislaby district. Tbe Millepore Oolite in the Humber area was used in building the Holderness Monasteries and later, the Hull Docks. The Kellaways Rock has been used in the Scarborough district, and the Lower Calcareous Grit in the Howardian Hills is locally important. The fine white Hildenley Limestone was used in the interior work of Kirkham Abbey, near Malton.

At tbe south end of the Lincolnshire Wolds, around Salmonby, the Spilsby Sandstone is suitable for building purposes, while farther north the Tealby Limestone has been used around Tealby and Walesby and the Totternhoe Stone in the Chalk has been employed in the construction of Louth Abbey.

Bricks and Tiles.—The Keuper Marl at Bishop Wilton in East Yorkshire has been dug for bricks in the past. The Middle Lias clays around Lincoln, the Estuarine Shales on the Yorkshire Coast, the Blisworth Clay in north Lincolnshire, and the Kimmeridge Clay in Lincolnshire, the Vale of Pickering and Howardian Hills, have all been used in the brick and tile industry. These sources are now largely disused in favour of the thick masses of boulder clay which are actively worked in many localities. Associated with the Millepore Oolite around Whitwell is a seam of fine earth which the Romans used for pottery making.

Road Metal.—Throughout north Yorkshire the Cleveland dyke is a principal source of road metal; it is worked in open quarries or mined at intervals along its outcrop from Fylingdales Moor, near the coast, westward to Stainton and Ayton. Many of the harder Jurassic beds, though inferior to the dyke, are used locally; in the Howardian Hills the Brandsby Roadstone (Grey Limestone Series) is worked about Gilling and Brandsby, and the Moor Grit is similarly employed locally north of the Esk.

Refractory Sands.—The Upper Estuarine and Kellaways sands in the Derwent Valley and Humber district have a high silica content and have been worked for refractory and moulding purposes in these areas at Huttons Ambo and Burythorpe, near Malton, and at South Cave, north of the Humber. In the vicinity of Scunthorpe, blown sand is used in laying out pig-iron beds.

Gravel and Sand.—Gravels and sands of glacial origin cover extensive areas in tbe vales of York and Trent and in the Vale of Pickering, and they are widely used for constructional purposes.

Water Supply.—The principal sources of water supplies in this area are the Chalk, the Jurassic sandstones and limestones and the Triassic sandstones, tbe latter being reached only at depth in the vales of York and Trent.

Many strong springs issue from the base of the Chalk along the escarpment of the Yorkshire and Lincolnshire Wolds, and the location of many villages has been determined by this line of springs from the south side of the Vale of Pickering southward to the Lincolnshire Fens. Over the greater part of the Wolds eastward to the coast water supplies are also obtained from springs in the narrow valleys which penetrate and dissect the Chalk area or from borings and wells sunk directly, or through the Drift, into the Chalk. The Spilsby Sandstone is a good water-bearing horizon for numerous villages in south Lincolnshire.

The Lincolnshire Limestone throws out numerous springs along the western escarpment, and smaller supplies are locally obtained from the underlying Northampton Sands. In Yorkshire the Corallian Series is becoming increasingly important as a source of water, which is being taken to areas far beyond the area of outcrop of the series. Copious springs are thrown out along the fringe of the Vale of Pickering where the Kimmeridge Clay is faulted down alongside the Corallian beds, resulting in a noticeable line of villages on the sites of the natural supplies. Borings sunk into the Corallian beds invariably tap supplies under artesian pressure, as at Irton near Scarborough. Of the Middle Jurassic rocks, the Moor Grit and thick sandstones of the Lower Estuarine Beds yield adequate supplies locally in Cleveland and the North Yorkshire Moors. Water from the Keuper is generally hard and gypsiferous, but it is eminently suitable for brewing for which it is used at Newark, Retford, Boroughbridge and elsewhere. The Keuper Sandstone gives a good supply of hard water at depth at York, Selby and Goole.

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XI. GEOLOGICAL SURVEY MAPS AND MEMOIRS AND LIST OF OTHER GENERAL WORKS DEALING WITH EAST YORKSHIRE AND LINCOLNSHIRE

A COMPLETE LIST of maps and publications dealing with this district published by the Geological Survey is given below, but the remaining literature is so extensive that only a selection can be given here.

GEOLOGICAL SURVEY PUBLICATIONS[1]

Maps

(*a*) Dn the scale of 4 miles to 1 inch: *colour-printed.*

Sheet 4. Part of Yorkshire. Solid*.
Sheet 7. Leeds, Manchester and York. Solid.
Sneet 8. Flamborough Head and Grimsby. Solid and Drift.
Sheet 11. Part of Lincolnshire. Solid.
Sheet 12. Part of Lincolnshire. Solid and Drift*.

(*b*) Dn the scale of 1 mile to 1 inch: *Old Series, hand coloured.*

Sheet 69. The Wash, Boston, &c. Drift.
Sheet 70. Newark, Grantham, Sleaford, &c. Solid and Drift.
Sheet 83. Lincoln, Horncastle, Gainsborough, &c. Solid and Drift.
Sheet 84. Coast of Saltfleet to south of Skegness, &c. Drift.
Sheet 85. Spurn Head, Great Grimsby, &c. Drift.
Sheet 86. Hull, the Estuary of the Humber, &c. Solid and Drift.
Sheet 93 N.E. York, North Grimston. Solid.
Sheet 93 S.E. Selby, Pocklington. Solid.
Sheet 94 N.W. Driffield. Solid.
Sheet 94 N.E. Bridlington, &c. Solid.
Sheet 94 S.W. Beverley, Market Weighton. Solid.
Sheet 95 N.W. Scalby, Hackness, Robin Hood's Bay. Solid.
Sheet 95 S.W. Scarboro', Filey, Hunmanby. Solid.
Sheet 95 S.E. Coast from Flamboro' Head to Filey Bay. Solid.
Sheet 96 N.W. Northallerton, Stokesley, &c. Solid.
Sheet 96 N.E. Egton, Rosedale, &c. Solid.
Sheet 96 S.W. Ripon, Thirsk. Solid.
Sheet 96 S.E. Vale of Pickering, Malton, Helmsley, &c. Solid.
Sheet 104 S.E. Coast at Whitby. Solid.
Sheet 104 S.W. Redcar, Guisboro', &c. Solid.
Sheet 103 S.E. Stockton, Yarm, Middlesbro', &c. Solid.

New Series: colour-printed. Drift.

Sheet 33. Stockton, Darlington, Middlesbro', Yarm.
Sheet 34. Guisboro', Redcar, Saltburn, Staithes.
Sheet 35 with 44. Hackness, Robin Hood's Bay, Scalby, Whitby*.
Sheet 42. Northallerton, Part of Cleveland Hills, Stokesley.
Sheet 43. Part of Cleveland Hills, Egton, Lewisham, Rosedale.
Sheet 52. Ripon and Thirsk.
Sheet 53. Helmsley, New Malton, Pickering.
Sheet 54. Scarborough, Filey, Hunmanby*.
Sheet 55. Coast from Flamborough Head to Filey Bay.
Sheet 62. Harrogate.
Sheet 63. Millington, North Grimston, Stillington, York.
Sheet 64. Great Driffield*.
Sheet 65. Bridlington, Skipsea.
Sheet 71. Fulford, Pocklington, Selby, Spaldington.
Sheet 72. Beverley, Market Weighton.
Sheet 73. Coast from Hornsea to Tunstall.

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[1] Stocks of Survey publications were destroyed by enemy action. Those marked with an asterisk are now available.

(*c*) Quarter-inch to 1 mile Gravity Overlay map
Sheet 11 (1956). Stockport, Lincoln, Wolverhampton, Stamford.

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(*a*) General Memoirs:

1877 SKERTCHLY, S. B. J. Geology of the Fenland.
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1892-5 FOX-STRANGWAYS, C. AND H. B. WOODWARD. The Jurassic Rocks of Britain. 5 Vols. Vols. i and ii (Yorkshire).
1900-4 JUKES-BROWNE, A. J. Cretaceous Rocks of Britain. 3 vols.

(*b*) Sheet Memoirs:

1880 (2nd Edition 1904). FOX-STRANGWAYS, C. Geology of the Oolitic and Cretaceous Rocks south of Scarborough.
1881 FOX-STRANGWAYS, C. Oolitic and Liassic Rocks to the north and west of Malton.
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1890 USSHER, W. A. E. Geology of Parts of North Lincolnshire and South Yorkshire.

(*c*) Mineral Resources Reports:

1915 (2nd Edition 1918; 3rd Edition 1938). SHERLOCK R. L., AND B. SMITH. Gypsum and Anhydrite. *Spec. Rep. Mineral Resources of Great Britain.* Vol. iii.
1920 LAMPLUGH, G. W., C. B. WEDD AND J. PRINGLE. Iron Ores: Bedded Ores of the Lias, Oolites and Later Formations. *Spec. Rep. Mineral Resources of Great Britain.* Vol. xiii.
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1925 HALLIMOND, A. F. Iron Ores. Bedded Ores of England and Wales. *Spec. Rep. Mineral Resources of Great Britain.* Vol. xxix.

(*d*) Water Supply Memoirs:

1904 WOODWARD, H. B., AND OTHERS. Water Supply of Lincolnshire.
1906 FOX-STRANGWAYS, C. Water Supply of the East Riding of Yorkshire.

(*e*) Economic Memoirs:

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1951 HOLLINGWORTH, S. E., AND J. H. TAYLOR. The Mesozoic Ironstones of England. The Northampton Sand Ironstone: Stratigraphy, Structure and Reserves.
1952 WHITEHEAD, T. H., W. ANDERSON, V. WILSON AND D. A. WRAY. The Mesozoic Ironstones of England. The Liassic Ironstones.

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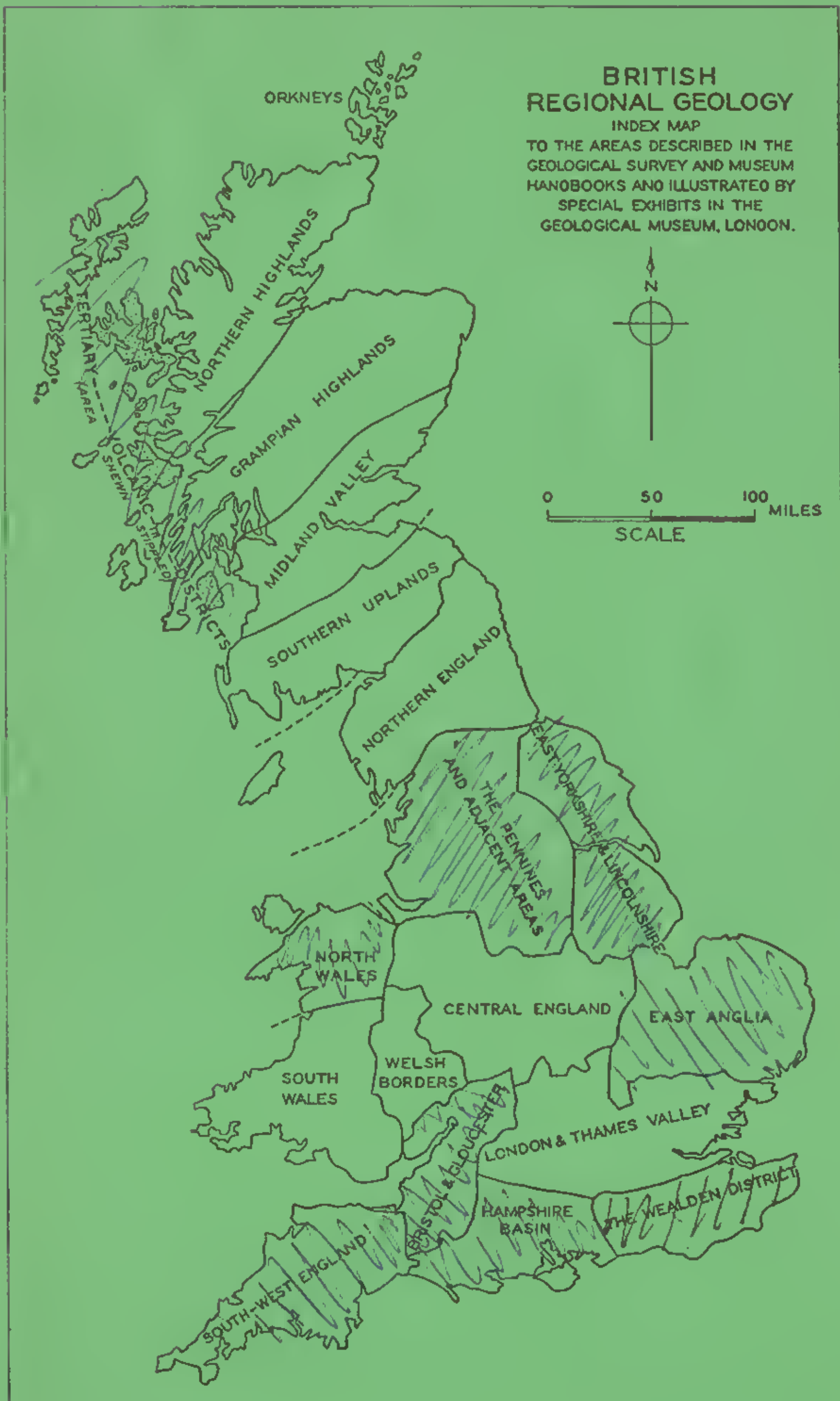
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